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Dairy cow behaviour and automatic milking.

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Dairy cow behaviour and automatic milking

by

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Abstract

Voluntary automatic milking is a system whereby dairy cows can be milked as the cow desires without routine human intervention.

Motivation to be milked was studied in a Y-maze and an automatic milking system (AMS). In both motivation to be milked was variable. In the Y-maze some early lactation cows chose to be milked every $3^1/_2$ hours five times per day, but there was much individual variation. Late lactation cows did not choose to be milked less often than the early lactation cows. When given the choice to be milked or fed concentrate in the Y-maze, early lactation cows always chose to eat. In the AMS mean attendance increased from 1.1 visits/cow/day when they were not fed concentrate to 2.8 visits/cow/day when they were fed concentrate.

The effects of feeding in the AMS on attendance were studied. Feeding concentrate in the parlour had no effect on attendance or the number of milkings. The AMS exit area feed type (where the cows had to visit the AMS to reach the food; either forage or concentrate) however, had a significant effect on attendance (forage: 6.0 visits/cow/day, concentrate: 4.1 visits/cow/day, s.e.d=0.25) but only a small effect on the frequency of milkings (forage: 2.6 milkings/cow/day, concentrate: 2.4 milkings/cow/day, s.e.d=0.06). Feeding forage in the exit area, as opposed to freely available in the bedded area, significantly reduced the total forage feeding time (209 vs 289 minutes/cow/day, s.e.d=33.6), and the number of bouts (4.9 vs 7.9 bouts/cow/day).

Feeding cows in the parlour increased the level of shuffling during the automatic teat cup attachment process (6.7 vs. 3.4 shuffles/cow/milking, s.e.d 2.07). There were no other behavioural effects or any effects on their milking characterisitcs.

Future automatic milking systems could feed concentrate in the exit area as the lure to attract cows into the system. There is no requirement to feed cows while they are being milked.

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Declaration:

I certify that the work embodied in this thesis is the result of my own investigations.

The views expressed in this thesis are those of the author and not of the university

Neville Prescott

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Abbreviations

AM	Automatic milking
AMS	Automatic milking system
AOV	Analysis of variance
cm	Centimeter
Conc.	Concentrate (cake)
Conc2	Concentrate fed in exit area in period 2
CR	Coarse Ration (Dalgety)
d	Day
d.f.	Degrees of freedom
DIM	Days in milk
Diversion	AMS stage; diversion race
E	Expected
Exp	Experimental
fnf	Fed or not fed in the parlour
h	Hour
hrs	Hours
HGMS	AMS stage; holding gate to milking stall
hz	Hertz (cycles per second)
ID stall	Identification stall
IDHG	AMS stage; Identification stall to holding gate
kg	kilogram
kpa	kilopascals
l	Litre
L	Lettuce
lact.	Lactation
m	Metre
max.	Maximum
Milk out	Time taken to extract all available milk from the cow's udder
min.	Minimum
MJ	Mega-Joules
MSEA	AMS stage- Milking stall to exit area
mm	Millimeter
n.a.	Not applicable
NC	Normal Concentrate (BOCM/Pauls)
no.	Number
nR.E.M.	Non-rapid eye movement
n.s.	Not significant
O	Observed
p	Probability
Parlour0	Nothing fed in parlour
Parlour1	1kg fed in the parlour
Parlour2	2kg fed in the parlour
PN	Pasture Nuts (Dodson and Horrell)
r	Regression coefficient
R.E.M.	Rapid eye movement
s	Second
S	Silage

SB	Sugar beet pellets (Trident Feeds)
s.d.	Standard deviation
s.e.d.	Standard error of the difference
Sig	Significance
Forage1	Forage fed in exit area in period 1
Forage3	Forage fed in exit area in period 3
Silconc	Forage or concentrate fed in the parlour
SRI	Silsoe Research Institute
SW	Sugared water
VM	Vegetable mix
WSB	Wet Sugar Beet
WSSB	Wet Sugared Sugar Beet

...*Group C* (Yearling Heifers): Upon lying down, 1 animal immediately began to smell the observer's foot. By the end of 2 min, 5 animals were smelling his feet, legs and buttocks; one was trying to lick the camera lens. Rapid approach behaviour continued with more and more animals gathering around, smelling, licking and looking intensely at the observer, his camera and his notebook. The observer's clothing became wet from their saliva, and by the time 9 minutes had elapsed, some excited animals began to mount one another, stumbling about close to the reclined observer, causing him to note that he feared being trampled at any time...

...*Group E* (Mature Milch Cows): The observer was reclined within reach of 1 animal, and another was reclining within his reach. both cows continued their ongoing activities (grazing, chewing cud and "loafing"), as did the remainder of the herd. A few animals, when walking down the path approximately 1.5 m away from the observer, stopped momentarily, looked at him, then continued on their way, carrying out routine activities. After 7 min had elapsed, 1 animal approached, smelled the observer's knee, and began to lick and nibble his notebook, which was difficult to extract from her mouth. Five minutes later she began to solicit petting (not showing a typical investigatory pattern) by placing her forehead against that of the observer, shaking and rubbing her head against his with her horns bracketing the observer's skull. After approximately 1 min, she moved away and lay down (much to the observer's relief)...

(From Murphey et al (1981); Age group differences in bovine investigatory behaviour. Developmental Psychobiology 14: 117-125)

CHAPTER 1

INTRODUCTION

1 INTRODUCTION

Dairy cow behaviour is pivotal to the successful application of voluntary automatic milking. The constraints imposed by the cow's behaviour will ultimately determine the practicality and design of any commercial system. The potential of voluntary automatic milking is to revolutionise the milking and management of dairy cows but can be seen as one step in the development of machine milking (Schon et al. 1992, Jongebreur 1992, Dodd and Hall 1992).

Automatic milking seeks to replace the constraints of fixed time milking (two or more times per day), imposed by the needs of the herdperson, with a more flexible regime. Cows may be able to visit the system individually, and at a higher frequency than is generally the case now, without increasing labour costs, and at times that suit the cow rather than the herdsperson.

Various advantages have been claimed to derive from automatic milking. The cows could be milked on demand without having to wait in a collecting yard (the conventional method). In addition, multiple health checks could be made with sensors, as yet undeveloped, every time the cow attends the milking stall (Mottram and Street 1992) thereby improving the monitoring of the cows' health and probably their welfare.

For the operator, the system could remove the monotony associated with milking time (Seabrook 1992) and allow more time for other, often neglected, tasks such as calf rearing (Mottram and Street 1992). The incidence of injuries should decline with the removal of repetitive and straining actions during milking, (Lundqvist 1992). The farmer, who may also be the operator, could also benefit. More frequent milkings will result in 10-15% higher milk yields (e.g. Hillerton and Winter 1992, Knight and Wilde 1993) and more frequent health checks should help to reduce the incidence of disease.

There may be negative aspects to automatic milking. On welfare grounds, it might be argued that cows cannot sustain ever increasing yields indefinitely without an infringement of their welfare (Webster 1995). Making frequent milking more practical may contribute to, or accelerate this trend. Alternatively dairy farm workers may feel that this technology may threaten their jobs (Seabrook 1992). Also implementation of the system may fail if it becomes too expensive or complicated (Seabrook 1992, Smith 1993).

Research into automatic milking has been confined to Europe and Japan. Frost (1990) identified seven organisations researching automatic milking in Europe. Two systems were commercially available in 1995, the Prolion system (marketed in the UK under the trade name of Liberty Milking Systems) and the Lely Milking System (the `Astronaut' system). These systems conformed to a similar general design but differed in detail, for example how they found and attached the teat cups to the teat. In general cows moved into a stall situated in the living area which directed them back either into the living area or into the milking stall. Here sensors detected the location of the teats and attached the cups to them. After milking the cow was directed back to the main living area. The state of the technology was described in Ipema et al. (1992).

Automatic milking systems (AMS) require that the cows who use them do so appropriately. There will be a number of behavioural criteria which the cows must exhibit if the system is to work reliably, and three are discussed here. First the cows must visit the system at an appropriate frequency. Below a certain level of attendance (less than twice per day) the cow's milk production may be reduced, since the cow can only store a certain amount of milk in her udder before autocrine feedback inhibition reduces alveolal milk secretion (Wilde and Peaker 1990). The welfare of the cow may also be reduced through an increased risk of mastitis associated with reduced milking frequency (Hillerton and Winter 1992) and potentially from a reduced level of, as yet undeveloped, health monitoring. Conversely a cow who visits the system too frequently will waste a scarce resource, since the system will spend more of its time unprofitably diverting cows rather than profitably milking them. The spatial distribution of those visits is also important, for an individual cow they should be well spread through the day. Cows who visit the system frequently for only part of the 24hrs may not be milked as often (if they attend too soon after the last milking) or show a reduced yield response, compared with cows who attend at a similar frequency uniformly throughout the 24hrs. A system that can attract high yielding cows more often than low yielding cows would also be desirable if the resource is restricted. This is because a 10-15% increase in yield of a low yielding cow is less than an equivalent increase of a high yielding cow. Therefore it would be more appropriate to milk the high yielding cow more frequently than the low yielding cow.

The second area of cooperation between the cow and an AMS is that once in the system the cow must move through it quickly. A cow idling in any part of the system will prevent another from entering, and again if the AMS is a limited resource this will be wasteful of its time. For example consider a system available for 18hrs per day aiming to milk cows three times per day. If each cow spent 10 minutes in the system, the maximum number of cows per milking stall would be 36. If the time spent in the system rose to 15 minutes per cow, the maximum number of cows per milking stall would be 24. This presumes that a cow is always waiting to enter the AMS and that no cow comes through more often than three times per day.

Thirdly, the cows must behave in a way that allows the system to perform its function, that of milking. In the milking stall the cows must behave in a way which allows the robot to clean her teats, and attach and remove the teat cups. Cows who persistently kick or who are restless in the milking stall will compromise the successful teat cup attachment rate.

The first aim of this thesis was to explore the motivations of cows to visit the AMS. This concentrated on motivation to be milked and to be fed, since these seemed to be the most important. Other factors, which affected variations in individuals attendance rates were also considered, these included stage of lactation, hierarchical dominance rank, fearfulness and age. Understanding the main reasons why cows may have visited the system was important in determining the possibilities and constraints that the cows' behaviour imposes on the system's design. For example if cows are strongly motivated to be milked *per se* then there would be no need to feed them when they visit the AMS as an added attractant. If cows are only weakly motivated to be milked however, there may be a need to provide food rewards in the AMS. Feeding in the AMS offers a number of alternatives regarding the location and type of food reward, for example either forage or concentrate can be fed in the exit area of the AMS. The second aim was therefore to study the effect of this, and feeding or not feeding the cows in the milking stall, in relation to its effect on the level and temporal distribution of attendance. The effect on the cows' behaviour both in and outside the AMS and on the time taken by the cows to move through various parts of the system was also studied. From these studies it was possible to suggest alternative design features for an automatic milking system based on the behaviour of the cow.

2 DAIRY COWS (*Bos taurus*) ON TRADITIONAL COMMERCIAL FARMS

2.1 The practise of dairy farming

In the Western world the lives of the majority of dairy cows are similarly constrained. They generally have their first calf between two and three years old (with a trend towards the younger end of the range), and start producing milk. Most dairy farmers generally aim to manage their cows such that they produce one calf, and undergo one lactation, per year (termed the calving interval). A pregnancy lasts for 280 days and a lactation for 305. Macmillan (1996) reported that for 136 farms in one recording scheme (the Dairy Information Service, Reading University) the mean calving interval was 380 days, often because the cows failed to conceive; an average of 2.1 serves were needed to initiate pregnancy. The farmers also failed to inseminate the cow at the appropriate time; the average heat detection rate was 55.5% (Macmillan 1996). During a lactation a Holstein/Friesian dairy cow will produce a mean milk yield of 7,000l (The Federation of United Kingdom Milk Marketing Boards, 1993), but this may be lower or higher depending on the genetic potential of the cow and the management system. On average 25% of the dairy herd is culled every year (Esselmont 1992). The cited reasons for culling often include breeding problems (33.8%), low yield (15.9%), mastitis (12.5%) and lameness (7.4%) (Young et al.1983). It has been suggested that this situation could be more usefully described as the cows being `worn-out' through the stress of milk production (Webster 1995). The level of mastitis and lameness in dairy herds supports Webster's argument. Clarkson et al. (1996) reported that the prevalence of clinical lameness was 20.3%. Beaudeau et al. (1995) suggested that the 28.4% of cows have mastitis during a lactation, and 14.9% exhibit clinical lameness.

Webster (1995) contended that the modern dairy cow is under considerable metabolic stress. In peak lactation a cow may produce in excess of 40l of milk per day, the nutrients for which are sourced from the food that she eats and her own body reserves. During the first few weeks of lactation, dairy cows lose weight rapidly and daily milk yield rises. Gibb et al. (1992) showed that the average weight loss for 54 second to fourth parity Holstein-Friesian dairy cows was 43.1kg in the period from calving to the eighth week of pregnancy. This weight loss included 37.4kg of fat and 5.6kg of protein from the empty body weight. Senatore et al. (1996) suggested similarly for 40 first parity Holstein heifers who lost approximately 48kg of body weight in the first six weeks of lactation.

At 18 days after calving the heifers had a mean energy deficit of 50.5 MJ of energy per day. For this period of weight lose we may suppose that the dairy cow is hungry but is constrained from becoming satiated. Webster (1995) suggests that these constraints may include the palatability of the silage, the dilution of the diet, i.e. the cow does not have the physical capacity in her gut to eat enough food, or that the cow is unable to meet all the time requirements for resting and eating.

Automatic milking systems must be designed so that they do not exacerbate these twin potential threats to the dairy cow's welfare (disease and production levels). Since automatic milking is a novel management tool, the potential for improving the welfare of the dairy cow should also be considered in any design.

3 DAIRY COW BEHAVIOUR

There are three major activities in which a cow may engage during her day. These are resting, eating and being milked. Some behaviours may be included under two or more of these major behavioural categories. For example a cow may `drowse' and ruminate simultaneously thereby resting and eating. A small sample of a large literature regarding the amount of time spent lying and eating (excluding ruminating) for Holstein-Friesian dairy cows is shown in table 1.1

Table 1.1 Proportion of time spent lying and eating by dairy cows

Researchers	Lying (% of 24 hrs)	Eating (% of 24 hrs)
Phillips and Schofield (1994)	52	29
Dado and Allen (1994)	-	21
Bouissou and Signoret (1971)	39.6	17.8
Albright (1993)	50	13.2
Albright and Timmons (1984)	42.6	25.6
Prescott (1992)	32	24

3.1 Interaction between cattle and automatic machines

There are three main areas in milk production where cows interact with machines. These are in the milking parlour, automatic concentrate feeders and automatic milking systems (where a few studies have been conducted). Studying these areas may help us to understand how dairy cows will respond to voluntary automatic milking. It is also important to consider the individual characteristics of cattle that might introduce variation in their response to automatic milking systems. These characteristics include rank, fearfulness and age.

3.1.1 Individual characteristics of cattle

Rank order in a group of cattle can be defined as the sum of agonistic interactions between all pairs or `dyads' of animals (Beilharz and Zeeb 1982). Cows of high rank dominate most other cows whereas cows of low rank dominate few animals. Rank order may affect how often and in what order the cows enter the AMS, since the food reward provided in the AMS may create competition to enter. The higher and lower ranking cows may thus get more and less access respectively to the AMS.

In any dyad one or both cows may try to dominate the other by fighting. Some agonistic interactions however may be very subtle since a very low ranking animal may avoid contact with another very high ranking cow. The only evidence of this sort of relationship may be a lack of social interaction of any kind. Between these two extremes lie agonistic behaviours such as threatening and submissive postures. Various agonistic behaviours were pictorially represented by Dickson et al. (1966). Rank order in cattle probably serves to reduce the amount of competition within a group since each cow will know her rank relative to each of the other group members which obviates the need for outright aggression (Phillips 1993, Beilharz and Zeeb 1982, Hughes 1977c). Rank has been not been consistently correlated with measures of size, age or production level (Arave et al. 1975, Beilharz and Mylrea 1963, Dickson et al. 1966, Miller and Wood-gush 1991, Collis 1976, Beilharz et al. 1966, Beilharz and Zeeb 1982, Dickson et al. 1970). This is probably because rank has a degree of inertia, cow A may be expected to be of higher rank than cow B but fail actually to be so because of some historical factor. For example she may have been severely bullied by cow B when she first entered the herd as a heifer and is now disproportionally frightened of cow B. This probably contributes to `nonlinear' orders where cow A is dominant to cow B who is dominant to cow C who is in turn dominant to cow A. These are sometimes called circular relationships (Appleby 1983) or reverse bunting (Beilharz and Mylrea 1963).

One important aspect of the psychology of the cow relevant to the development of the AMS is fearfulness. Webster (1995) defined fear as;

"..a conscious, rational and emotive response to a perceived

threat that acts as a powerful motivator to action designed, where possible, to evade that threat. It is also an educational experience, since the memory of previous threats, action taken in response to those threats and the consequences...will obviously determine whether the experience will be more or less fearful next time around."

Fearful cows may be less willing to use the system than `bold' cows if they find it threatening. Once in the system, timid cows may move through the system slower and behave differently in the milking stall than bolder cows.

Kilgour (1975) used an open field test to assess the `emotionality' of cattle. Cows were allowed into a $22m^2$ arena and their movement around the arena measured from a grid painted on the floor. In addition, two experienced dairy technicians subjectively rated the cows on temperament. The results showed that the technicians did not agree with each other and that the interpretation of the ambulation scores was difficult, even regarding whether high ambulation scores related to calm or fearful temperament. Kovalcikova and Kovalcik (1982) used a similar method in trying to correlate milk production with spontaneous ambulation; young cows showed some correlation but older cows did not. Dellmeier et al. (1990) found that housing affected calves performance in an open-field test, calves kept in close confinement showed greater locomotory behaviour. Tulloh (1961) studied cattle's behaviour in entering a crush as a measure of temperament and found that there were significant breed effects. MacKay and Wood-Gush (1980) suggested that an animal's reaction to a novel situation was a combination of curiosity to explore and neophobia. In the AMS it would be expected that visits made out of curiosity would rapidly decrease since the system design and functioning varies little from visit to visit. Fear of the system may however remain high for fearful cows, especially if they do not use the system as often as bold cows. Thus, measures that include aspects of curiosity, for example the open field test, may confound fearfulness with curiosity.

Age may affect a cow's interaction with the milking system if curiosity or fearfulness change with age. Murphey et al. (1981) showed that investigatory behaviour was greater in two year old heifers than older cows. Kempkens and Boxberger (1987) showed that cows moved around housing less than heifers. If old cows move around less than young cows, then they may interact less with the AMS.

3.1.2 Dairy cow interaction with milking machines

Milking machines were developed at the turn of this century (Dodd and Hall 1992), and now practically all dairy cows in the UK are milked by machine.

The milk let-down process, whereby the milk stored in the udder is made available for removal, is a conditioned reflex (Cowie 1983, Nickerson 1992). In *Bos taurus* breeds (e.g. Holsteins, Friesians) milked in parlours, the stimulus initiating the conditioned reflex may be the sound, smell or sight of the parlour. Willis and Mein (1982) successfully trained cows to let-down in response to a blue disc 33cm in diameter. *Bos indicus* breeds (e.g. Zebu, Brahmin) generally need the sight of the calf before they will let down their milk (Phillips 1993). This difference in ease of let-down may be a response to selection of *Bos taurus* cows for ease of machine milking.

Let-down is facilitated by the hormone oxytocin, whose secretion is stimulated by the conditioning stimulus. For effective removal and fast milking, oxytocin must remain continuously elevated during milking (Bruckmaier et al. 1994). Hand-milking (Gorewit et al. 1992), pre-milking stimulation (Mayer et al. 1984, Sagi et al. 1980), feeding concentrate (Svennersten et al. 1990, Svennersten and Samuelsson 1992) and the presence of calves (Tancin et al. 1994) all improve the let-down reflex, probably through the effects of the hormone oxytocin. Other factors inhibit the let-down reflex, including unfamiliar surroundings (Bruckmaier et al. 1993), attributes of the stockman or milker (Seabrook 1992, Seabrook 1994), jet aircraft noise (Head et al. 1993), small stray electric currents (Henke-Drenkard et al. 1985, Blodgett et al. 1949), exploding paper bags and cats *(sic)* placed on the cow's back (Ely and Petersen 1941). Cowie (1983) and Nickerson (1992) suggested that stress, excitement, fear or pain can inhibit the let-down reflex since they increase adrenalin levels, reducing blood flow to the udder and preventing oxytocin from reaching it.

When cows enter parlours voluntarily they do so in a particular order (Albright et al. 1992, Rathore 1982, Soffie et al. 1976, Winter 1993). This order does not appear to be strongly related to dominance rank (Dietrich et al. 1965, Beilharz et al. 1966, Dickson et al. 1966, Soffie et al. 1976). The effect of stage of lactation on the order of attendance is also unclear. Rathore (1982) and Ferguson (quoted in Albright et al.

1992) both found that high yielding cows entered the parlour earlier than low yielding cows. However, Winter (1993) found no significant relationship. Phillips (1993) and Rathore (1982) have both suggested that high yielding cows are more motivated to be milked to relieve the pressure or weight of the udder. Phillips (1993) also suggested that when concentrates were offered in the parlour, higher yielding cows would be hungrier than low yielding cows and hence more inclined to enter the parlour earlier than low yielding cows. Albright et al. (1966) trained cows to enter the parlour in a different order to that which the cows normally showed, by calling each individually. 70% of the cows entered when called and a further 15% found their place in the order without being called. 15% did not respond and failed to find their place in the order.

In the past, cows were fed concentrate in the parlour probably because this was the only time that they could be fed individually. Latterly totally mixed rations (TMR) have become more popular. By this feeding method the cow receives all her nutrition in a single food which is fed *ad lib.* but not in the milking parlour. Svennersten et al. (1990) showed that milk yields rose when cows were fed concentrate while being milked, as opposed to feeding concentrate elsewhere. This phenomenon is probably mediated through the hormone oxytocin which rises to facilitate let-down but also rises in response to feeding. The cumulative effect probably leads to a more intense and longer oxytocin peak which allows more milk to be extracted from the udder (Svennersten and Samuelsson 1993, Svennersten et al. 1990).

The evidence regarding the interaction between the cow and machine milking implies that milking is not aversive to most cows. If it were, the let-down reflex would be inhibited and cows would not attend the milking parlour voluntarily. It has been shown that milking increased heart rate (Royle et al. 1992b, Royle et al. 1992a, Hopster et al. 1992) which may be consistent with stress. Alternatively tachycardia could have resulted from an increased level of physical effort, arousal, because of feeding, or through the action of oxytocin.

For the cow, voluntary automatic milking may change the way they are milked in two main ways. First the cows will not have to wait to be milked. In conventional systems the length of time that a cow spends per day being milked (and this includes collection to, and return from, the milking parlour) may be two or three hours per day (personal observation), during which time they may not be able to eat or to lie down.

Various factors affect this including the size of batches in which cows are milked and whether an individual cow enters early or late in the milking order will affect this. If Webster's contention is correct, that cows have difficulty meeting both the time requirements of eating and resting, then removing two to three hours of potential eating or lying time out of a cow's day may exacerbate this situation.

The second main difference is that the cow will be able to choose when she wants to be milked. Conventionally cows are milked twice, or occasionally three times, per day at times dictated by the herdsperson, and this may or may not suit the cow's preference. In section 5.1 this situation is contrasted with the suckling behaviour of beef suckler cows and their calves, who have unrestricted access to each other.

3.1.3 Dairy cow interaction with automatic concentrate feeders

Automatic concentrate feeders are a means whereby individual cows can be fed a selected amount of concentrate outside the parlour. The feeders are activated by a transponder located on the cow. When a cow attends a feeder, she is recognised (from the transponder) and supplied with her ration. The free standing feeders are connected to a control computer with which the farmer can monitor and control any individual cow's concentrate consumption.

Automatic concentrate feeders are frequently used on dairy farms and offer the farmer the ability to feed individual cows different amounts of concentrate without the necessity to feed in the parlour, where feeding may extend the milking process (Whipp 1992). Collis (1980) showed that this method of feeding could provide cows with the desired level of concentrates and that the cows could rapidly learn how to use these systems.

Wierenga and Hopster (1988) showed that when cattle were allocated food on a fixed time schedule (i.e. a quantity of food presented after a certain period of time has elapsed) low-ranking animals had to wait for longer than high-ranking animals to access the feeders. When a variable time schedule was used, this difference disappeared (i.e. food presented incrementally after very short time intervals). They also showed that cows were more likely to interrupt their lying periods, and even reduced them, to visit the concentrate feeder on the variable time schedule. In an attempt to overcome the effects of rank and changes in lying behaviour, Wierenga and Hopster (1987) fitted five heifers and five cows with individual auditory signalling devices to call each individual cow to a concentrate feeder, when feeding was permitted. During the experiment the number of unrewarded visits dropped, implying that there was less modification of lying time and less bullying. The cows responded to the signal approximately 70% of the time. When they did not respond, they were generally lying but rarely eating or standing.

3.1.4 Dairy cow interactions with automatic milking systems

It is important to recognise the difference between frequent and voluntary milking. The latter is a system where the cow decides when she wants to be milked. Frequent milking, i.e. more than twice per day, can still be at fixed time intervals.

Rossing et al. (1985) detailed an experiment in which a voluntary milking system was simulated in a concentrate feeding box with the clusters being attached by hand. The cows visited the system on average 5.4 times (max 9.1, min 3.1), and were milked on average 4.0 times (max 4.8, min 3.0), every 24hrs.

Metz-Stefanowska et al. (1992) performed a similar experiment but here a concentrate feeder was available in the cubicles and in the milking stall (and the cows were milked automatically). Here a significant number of cows had to be manually presented to the milker because they had not visited of their own volition before the end of one of the three milking periods. As the experiment progressed, however, the proportion of `voluntary' milkings increased and it was reported that the cows became less nervous of the system (the cows had to be manually pushed out of the milking stall 38% of the time). Cows that came voluntarily to be milked showed a general uniformity of behaviour. One hour before presenting themselves at the milker the numbers lying started to decline and the numbers feeding and standing rose. The animals that failed to volunteer showed less organised behaviour before being manually collected and were often lying or feeding. After milking both groups showed similar behaviour, most cows feeding and then resting.

Winter (1993) showed that there were differences in the time spent feeding between cows milked two or four times per day. The higher frequency milking resulted in more time spent feeding and, presumably, more feed eaten. The total lying time was conserved although the number of lying bouts and the length of those bouts was affected.

There are two modes of operation for automatic milking. In the first, the cow must visit the AMS to get to a source of food (often forage). The cow enters the ID stall and the system decides whether the cow should be milked or diverted directly into the feeding area. This is called `active selection' in the literature (Ketelaar-de-Lauwere 1992, Winter 1993) but could also be called 'system' or 'operator' controlled. The second mode of operation is to allow the cow free access to the food from the living area without having to visit the AMS. This is called `passive selection' in the literature (Ketelaar-de-Lauwere 1992, Winter 1993) but could also be called `cow' controlled. Ketelaar-de-Lauwere (1992) suggested that operator control could be undesirable because it stresses the cow. This is because, to the cow, the system is unpredictable since she may not be able to predict whether she may be milked or not. It may also be aversive because the cow has to use one way races. Operator control does, however, ensure that cows will come to the AMS frequently because they need to eat. Ketelaar-de-Lauwere (1992) found that operator control reduced the time that cows spent eating silage and that the movement around the system was inhibited. Winter (1993) found a similar disruption to eating behaviour; the cows ate less often but each meal was longer. Winter (1993) also found a reduction in lying time when the cows were fed concentrate in the milking stall and forage in the exit area, as opposed to just being fed forage in the exit area.

Most automatic milking systems have a facility to feed cows while they are being milked (Artmann 1992, Winter 1993, Allen et al. 1992). Behavioural problems associated with feeding during milking include slow exiting because the cows are busy licking the bowl or waiting for more food (Whipp 1992). Whipp (1992) also suggested that cows are more restless when fed during milking because, when finished, they look around for more food and try to steal their neighbour's. This results in fighting and fidgeting, and consequently more eliminatory behaviour. Other problems include concentrate dust build up around the parlour and vermin may be encouraged into an area where food for human consumption is extracted and stored.

To milk a cow successfully, the robot must be able to attach the teat cups. This is best achieved when the cow is standing still; if the cow moves about in the stall the attachment rate may be reduced. Mottram et al. (1995) reported that in a trial 15% of all failed teat cup attachments were due to the behaviour of the cow, including kicking. Kicking may create problems if the teat cups are knocked off, since re-attachment of individual teat cups may be more difficult than in conventional systems. Feeding the cows during the attachment process may keep them quieter by distracting them from the workings of the robot and the stall. Two other benefits of feeding cows in the milking stall, specific to automatic milking, are, first, that in a voluntary system it may encourage them to visit. Secondly, on entering the milking stall, the feed, at the head of the stall, may encourage the cows to mount a step or put their heads into a yoke and move to the desired position (which may be dependent on the length of the cow).

4 MOTIVATION

If voluntary automatic milking systems are to succeed, the cow must be motivated to attend them at a frequency acceptable to the farmer. Understanding voluntary attendance to the AMS requires an understanding of the cow's motivations.

Motivation can be described as;

> *`The process within the brain controlling which behaviours and physiological changes occur and when'* (Fraser and Broom 1990).

In the development of motivational theory there have been two types of model. These are the hydraulic model (Lorenz 1950) and the homeostatic models (e.g. the state-space model, Sibly and McFarland 1974).

4.1 The hydraulic model

Lorenz (1950), suggested that animals have motivations that build up with time, like water behind a dam, creating a pool of what he termed `action specific energy'. This energy is released in the presence of an `innate releasing mechanism' and the animal performs some `appetitive behaviour' specifically to reduce that motivation. As the level of energy rises with time, so the strength of the innate releasing mechanism needed to release the action specific energy in the pursuit of appetitive behaviour falls. This forms the basis of Lorenz's dual quantification theory where the `discharge' of behaviour is controlled by the amount of action specific energy accumulated and the strength of the releasing stimulus. The accumulation of action specific energy may eventually reach a level where no releaser is needed to generate the appetitive behaviour. This type of behaviour was termed `energy accumulation activity' by Lorenz.

This model accurately describes some behaviours. Hunger is a motivation that builds with time since the last meal, as hunger increases the strength of the releasing mechanism needed to initiate eating is reduced. For example a very hungry animal will be prepared to eat less palatable food than a less hungry animal. Equally, a satiated animal would need a very powerful releasing mechanism, e.g. very palatable food.

While the Hydraulic model clearly describes some observed behaviours well, it has been criticised. The most important criticism is that it lacks any feedback mechanism from the consequences of behaviour; the action specific energy is discharged through the behavioural act. Manning (1979) quotes an experiment by Janowitz and Grossman (1949) which highlights this weakness. In this experiment dogs were oesophagally fistulated. This allows the feedback from the act of eating or from a full stomach to be teased apart. They found that if the dogs' stomachs were filled via the fistula (therefore without the dogs performing the behaviour of eating) the dogs failed subsequently to eat. The hydraulic model would predict that the dogs should have eaten since the action specific energy would not have been discharged without performing the behavioural act itself.

The hydraulic model also led to the concept of animals being driven to perform certain behaviours, since there is a strong mechanistic link between motivation and the behaviour it engenders. The concept of drives has been criticised for various reasons. Hinde (1959) suggested that drives could be misconstrued as being of unitary nature. For example a clear hunger drive or a clear thirst drive could be found, the activation of which would elicit the `final common path', i.e. feeding and drinking respectively. This is problematic because hunger drive, for example, may be made up of a drive to ingest certain nutrients such as vitamins, fats or minerals. This will therefore affect the animal's behaviour in finding food; i.e. there is no final common behavioural path in a `hunger drive'. Hunger therefore cannot be a unitary drive because it is made up of a number of different `hungers' corresponding to particular nutrients. The second problem is then where to stop defining what is a unitary drive. Further complications come when feeding is not the result of a need to ingest nutrients but occurs for other reasons; e.g. socially synchronised feeding in group animals, because the feed tastes pleasant, or because the animal needs to sample the feed available in the environment for future reference.

The final concern over the hydraulic model is the inaccurate use of the term energy. Energy cannot be a causal agent since it is a unit of capacitance (McFarland 1989).

4.2 The Homeostatic Model

Homeostatic models all depend on the central principle of an animal using feedback to compare its actual with its desired state.

In response to the problems of the hydraulic model McFarland (and other researchers) proposed a homeostatic motivational model. (Sibly and McFarland 1974). Essentially each of an animal's motivations are represented as vectors in multi-dimensional space, the neutral states of all motivations are found at the origin. An animal's motivational state is represented by a point in this multi-dimensional space, corresponding to its motivational state. Displacement of this point from the origin by some causal factor induces motivation and the animal strives, through appropriate behaviour, to return nearer to the origin. Wiepkema (1983) suggests a similar model with the animal comparing its actual state (or "istwert") with its desired state (or "sollwert"). Deviations of the istwert from the sollwert result in behaviours which attempt to redress that difference. Both these models use feedback from the consequences of behaviour to control behaviour.

One advantage of this model is that it makes no assumptions about the relationship between motivation and the behaviour it engenders. A particular motivation does not necessarily have to lead to a particular behaviour as the hydraulic model would imply.

The use of the feedback from the consequences of behaviour also fit some observations better than the hydraulic model. The Janowitz and Grossman experiment (1949) mentioned earlier could be explained by this model. When the animal compares its desired state (i.e. to be full) with its actual state (i.e. food in its stomach) there is no mis-match and hence no feeding motivation generated.

Other experiments however, have failed to support the homeostatic motivational models. Nicol (1987) showed the existence of `rebound' behaviour; the performance of behaviour at greater than normal levels by an animal after a period of restriction (Kennedy 1985). In this case wing-flapping and tail wagging in space deprived hens. This is more easily explained by the hydraulic model (in terms of the build up and release of action specific energy with time) than by the homeostatic models, which claim an increase in novelty of the deprived behaviour generating rebound behaviour, a claim experimentally discounted by Nicol (1987).

4.3 The State-space Approach and Cost vs. Reward

Larkin and McFarland (1978) studied the behaviour of doves *(Streptopelia risoria)*. They made doves both hungry and thirsty and, when provided with food and water, the doves divided their behaviour into eating and drinking, alternating between the two, until eventually the animals reached satiety. This they represented as a two dimensional graph with hunger on one axis and thirst on the other. As the doves ate and drank the step-like graph approached the origin. This simple approach, using only two motivations and plotting the doves' behaviour in two dimensions, showed the value of this method in representing an animal's motivational state as a point relative to an origin.

When a barrier was introduced between the food and the water, the length of time that the doves spent either drinking or feeding increased. This, as Larkin and McFarland (1978) explained, could be due to the increased level of work required to move from eating to drinking. In essence the `cost' of changing from eating to drinking (or vice-versa) was increased, hence the doves did not change behaviour as often as they had before the partition was introduced and presumably saved energy and time. This suggests that there are at least two mechanisms which affect motivational behaviour (McFarland 1989, Larkin and McFarland 1978). First, the strength of that motivation (or the degree of displacement of the animal's motivational state from the origin in the state-space model) and secondly the availability of the goal. An implication of this is that the strength of motivation to perform a particular behaviour can be measured by how hard an animal is prepared to work to achieve its goal.

5 MOTIVATIONS INVOLVED IN AUTOMATIC MILKING

This section will deal with three motivations which are important for automatic milking; motivation to be milked, to feed and to rest. Other motivations may also affect how cows will use the automatic milking system, for example some cows may use the system to hide from other group members. Some cows may be reluctant to use the AMS because it will mean separation from their herd.

5.1 Motivation to be Milked

There are at least three theories why a dairy cow may choose to be milked by an AMS. First is the discomfort of a large and distended udder (Phillips 1993, Rathore 1982). This may be true in the early stages of lactation when the udder's cell number, size and differentiation increase as milk yield increases up to a peak (Knight and Wilde 1993), the pressure of which may be relieved by milking. It is likely that three factors may be important here; size, weight and pressure. Cows may therefore learn that attending the AMS is positively rewarding if it relieves any physical discomfort. Artifical selection, or the milking regime, has led to hypertrophy of the modern dairy cow's udder (Webster, 1995) compared with, for example, a beef cow. Therefore, a dairy cow may need a greater quantity of milk in her udder to generate a motivation to be milked than other types of cow with smaller udders. Alternatively the twice daily milking regime may have desensitised the cow to the discomfort of a full udder, since this occurs frequently.

Secondly, cows may gain some psychological reward from being milked in that it fulfills some psychologically rather than physically-induced motivation. Mother-offspring interaction theory suggests a dynamic relationship up to weaning. Trivers (1974) suggested that as the young mature parental investment should decline. This serves two functions, first, it helps wean the offspring and second, it allows the parent to devote more resources to the latest offspring or *in utero* foetus. Blass and Teicher (1980) suggested a three stage mechanism for this. First, the mother initiates suckling, then suckling is initiated jointly, finally the young initiate suckling. They provide evidence of this in rats. Boe (1993) presented evidence from sows and piglets which also largely supported this. Recently, Bateson (1994) challenged this view with the suggestion that weaning is related to factors other than age of the young. He suggested that both the mother, and her young, monitor each other's state to determine the optimal weaning period. Deviations from Trivers' model may occur if the mother is not pregnant or the lactation has been disturbed, for example, by malnutrition. Gomendio et al. (1995) showed that maternal state affected when weaning occurred. Food-restricted rat mothers weaned their offspring later than food-unrestricted rat mothers. Deviations from Trivers' model by the offspring may occur because there may be benefits to be gained from weaning. The mother may be more useful to her young after weaning if she is in good condition (i.e. not exhausted by a prolonged lactation). Alternatively the development of the young may require a change from milk to solid food. The young may also fail to meet their nutritional requirements solely from their mother's milk. Thus, the weaning process may not be so much a conflict (Trivers 1974) as a mutual decision between the mother and her offspring (Bateson 1994).

In cattle, when a calf is newly born it actively seeks the cow's udder and teats. Ventorp and Michanek (1991) showed that by five hours post-partum 17 out of 21 calves had found their mother's udder and successfully sucked. The strength of this motivation to suck probably reflects the need to acquire passive immunity rapidly from the cow's antibody rich colostrum (Ventorp and Michanek 1991). Early in lactation a calf sucks between 5-8 times per day, however as the calf ages this declines to 3-5 times per day (Phillips 1993). Odde et al. (1985) showed that in free ranging beef cattle the most intense period of suckling coincided with dawn. Other peaks in suckling behaviour appeared during the day and at dusk. In this study, the calves sucked on average five times per day (range 1-11) but there was no effect of calf age on this frequency. In contradiction to this Day et al. (1987) showed that calves 52 days old sucked more than calves 167 days old (8.6 vs. 4.5 suckles/day) and that the older calves sucked for less time per day than the younger calves (64 vs. 44 minutes/day).

Beef cows exhibit a degree of lactational anoestrus (failure to conceive during lactation) when suckling their young. Failure by beef cows to re-breed after calving (lactational anoestrus) is a critical factor in their profitability and has therefore been subject to intensive research. This research has elucidated the following components of the hormonal reaction of cows to their calves. The reason for lactational anoestrus is the failure of the cows to exhibit the pulsatile release of luteinising hormone (LH) from the anterior pituitary necessary for ovulation. LH is released from the pituitary under the control of gonadotrophin releasing hormone (GnRH) secreted from the hypothalamus. It may be the failure of GnRH to stimulate secretion of LH, or opioid suppression of GnRH, generated by suckling, that is responsible for the maintenance of lactational anoestrus (Williams 1990). Silveira et al. (1993) showed that LH concentration and luteal activity were higher in cows sucked by alien compared to familiar calves. This suggests that the act of sucking itself was not a strong enough stimulus to generate lactational anoestrus but that sucking had to be performed by the cow's own calf. Stevenson et al. (1994) showed that mastectomised and intact cows had longer intervals to first ovulation than non-suckled mastectomised cows or mastectomised cows whose calves were not allowed inguinal contact with the cow. These two experiments suggest that suckling *per se* is not responsible for lactational oestrus whereas contact with the cow's own calf is. There is reason to suggest, therefore, that there may be some psychological factor influencing lactational anoestrus.

The relevance of some of these studies, using different species of animal, to dairy cows may be unjustified. However, beef suckler cows are often crosses between pure beef (e.g. Hereford) and dairy (e.g. Holstein and/or Friesian) breeds, and so comparisons may be more valid. There is little reason to suspect that the dairy cow's relationship with her calf is different to that between a beef suckler cow and her calf.

The above discourse suggests three implications for a cow's choice to be milked in an AMS. The first is whether the mother is motivated only to interact with or actually suckle the young, if the mother does not seek to suckle the young then we would expect no motivation generated from this source. The second is whether, if the mother does seek to suckle the young, under what mechanism does this occur. Bridges (1985) and Bridges and Millard (1988) showed that some hormones can elicit maternal behaviour in rats. These hormones included prolactin and growth hormone (or somatotropin), the concentrations of which change during lactation (Cowie 1983, Nickerson 1992). The behaviours elicited from the rat mother included pup retrieval, huddling and crouching into a suckling stance. The third implication is that we might expect any motivation to be milked to wane as lactation progresses and the hormone concentrations fall.

The third possible reason why a dairy cow may choose to be milked is that the process of let-down or milking is positively reinforcing. Let-down may be positively reinforcing due to the involvement of oxytocin. Milking may be positively reinforcing due to tactile stimulation of the cow's teats by the milking system. Therefore, the cow may associate the AMS with a positive experience.

The accumulation of milk in the udder and the positive reinforcement derived from let-down or milking (theories one and three above) would both be expected to generate attendance to the AMS. The generation of attendance to the AMS via the psychological reward hypothesis (theory two above), depends on two factors. First to what degree the cow associates a milking machine with a calf, and secondly from where the reward is derived, for example the cow may gain some psychological reward from seeing her calf sucking, or from the removal of milk from the udder. The latter may generate some attendance to the AMS whereas the former would not (unless the cow associates the milking machine with the calf).

5.2 Motivation to eat

Motivation to eat is important to automatic milking since food may be used to lure the cows into the system if they otherwise fail to attend at an appropriate frequency. From an operational point of view, knowledge of the factors affecting the number of eating bouts is important since this may drive the attendance rate and pattern to a large degree.

An animal may start to eat in response to a number of external and internal stimuli. Internal stimuli are mediated through hunger and may be a response to low levels of some metabolites in the blood (chemostatic theory) or lack of food in the rumen (bulk limiting theory) (McDonald et al. 1988). External stimuli may include group behaviour, innate diurnal rhythms (Arnold and Dudzinski 1978) or the presentation of a fresh or palatable food source (Winter 1993). Internal stimuli are related to the character of the food, especially important is the cellulose to starch ratio. Diets high in cellulose (e.g. silage) are fermented and broken down slower than diets high in starch (e.g. cereals). To progress from the reticulo-rumen into the omasum via the reticulo-omasal orifice, digesta must be less than $2mm^2$. Thus, foods that have a high cellulose content will pass through the gut slower than foods which have a high starch content. With diets high in cellulose the bulk limiting theory may take precedence over the chemostatic theory, i.e. gut fill will be reached before chemostatic controls are triggered. Diets high in starch may trigger chemostatic controls before gut fill is reached (McDonald et al. 1988). These theories suggest that different foods may cause a cow to modify her pattern and number of feeding bouts.

It has been suggested that the feed intake of a high yielding dairy cow in early lactation is not sufficient to supply the mammary gland with the energy and nutrients it requires (Webster 1983); the rapid weight loss (discussed in section 2.1) in early lactation cows is indicative of this. The implication is that the cow may be metabolically hungry and physically full at the same time (Webster 1995), i.e. the bulk limiting mechanism is activated before the chemostatic mechanisms. Since forage is often fed to supply the majority of a cow's nutritional requirements (all in the case of late lactation cows), systems which affect how the cows feed, for example using silage as a lure in the AMS (Ketelaar-de-Lauwere 1992, Winter 1993), may have repercussions. These might include predisposing the cows to metabolic diseases, e.g. ketosis and acidosis.

Webster (1995) suggested that feeding behaviour is under strategic and tactical control. Tactical feeding decisions would be based on proximate influences, for example gut fill. Strategic decisions would be based on the state of the animal relative to some reference point, for example if an animal is less fat than its reference point level then it may attempt to redress the difference.

Further to this, feed may possess properties which reduce appetite and alter feeding behaviour. Cushnahan and Mayne (1995) showed that cows fed excessively fermented silage had more feeding bouts and fed for longer, than cows fed restrictedly fermented silage. Nombekela et al. (1994) reported that cows rank tastes in the order sweet, sour, bitter, salt, while Kudryavtzev (quoted in Albright 1993) suggested that cows routinely fed silage had a reduced sensitivity to sour tastes. Adding tastes to foods can also change how they are eaten. Arave et al. (1983) showed that adding a flavouring agent reduced heifers preference for a particular feed.

Cows, being crepuscular (active at dawn and dusk), tend to eat more often at these times (Arnold and Dudzinski 1978, Albright 1993). Bouissou and Signoret (1971) showed that low ranking cows ate more often, for shorter periods and at different times than high ranking cows. Kenwright and Forbes (1993) also showed that low ranking cows ate for less time and at different times than higher ranking cows. Metz (1983) showed that reducing the length of the forage feed barrier caused cows to eat at different times during the day and there was an increase in the level of aggressive behaviour.

There are also environmental effects on eating behaviour. Winter (1993) showed that continuous lighting increased time spent feeding as opposed to a 12 hour light/ 12 hour dark day. Phillips and Schofield (1989) however, showed that cows given 18 hours of light did not eat for longer than cows given eight hours light. Muller et al. (1994) showed that in a hot sunny environment shaded cows ate for longer and more often during the day than unshaded cows.

Eating is also contagiously (socially) facilitated (Albright 1993), cows that see others eating may be more inclined to investigate and eat. Cows in groups often eat more than cows fed individually (Albright 1993).

5.3 Motivation to rest

Resting behaviour has implications for automatic milking for a number of reasons. It could be that reducing the time that cows spend being milked may give them more time to rest. Factors affecting resting behaviour may also influence attendance to the AMS since increasing lying time leaves less time for the cow to attend the AMS.

Resting is a general term implying anything from standing idle to actual sleeping. Ruckebusch (1972) defined four different resting states in cattle; alert, drowsing, non-rapid eye movement (nREM) sleep and rapid eye movement (REM) sleep. Only in REM sleep is there a marked reduction in respiration and heart rate, while muscle tone declines gradually through these phases. Ruckebusch (1972) and Ruckebusch et al. (1974) suggested that cows who were not allowed REM sleep exhibited irritability towards their handlers.

Balch (1955) suggested that cattle never seem to lose consciousness of the environment although there were periods where breathing rate and rumen contraction rate were significantly reduced, implying drowsing rather than real sleep. This, he suggested, was because some rumen functions, eructation and rumination, require a degree of consciousness which is lost when real sleep occurs. However, Ruckebusch (1972) recorded the sleeping and waking rhythms in cattle and found that cows sleep for about four hours per day, of which about one hour is REM sleep, made up of multiple episodes which may only last for two or three minutes, and drowse, during which rumination can occur, for a further 7.5 hours per day. Cattle seem able to modify their circadian sleep rhythm to cope with the prevailing husbandry requirements (Ruckebusch et al. 1974).

Most descriptive behavioural papers discuss lying and do not differentiate further.

Ruckebusch (1974) showed that cows can, in extreme circumstances, engage in nREM sleep while standing but not REM sleep. Presumably, lying offers more complete rest than idling and may offer some protection for low ranking cows. Metcalf et al. (1992) suggested that lying down generates a better blood supply to the udder which could increase milk yield.

Webster (1995) suggested that the work rate of cows producing milk in peak lactation may result in exhaustion. He also suggests that there is a conflict between the time requirements to eat and rest. Metz (1984) showed that restricting cows' access to a lying area for three hours induced them to lie when the restriction was lifted. After a period in which both feeding and lying were restricted, the cows chose to lie instead of feeding. Ruckebusch (1974) deprived cows of REM sleep and food for 12hrs and found that when the restrictions were removed the cows tended to feed preferentially to lying. Krohn and Konggaard (quoted in Arave et al. 1983) found raised levels of blood cortisol, indicating stress, in cows whose lying time was reduced by 75%. Friend et al. (1979) found that when cubicles were severely overcrowded the cows showed an increased adrenal response, again indicative of stress.

There are other factors which affect lying behaviour. Bouissou and Signoret (1971) showed dominance rank affected lying behaviour; low ranking cows appeared to lie for less time in total and had more and shorter lying bouts than high ranking cows. The type of cubicle (O'Connell et al. 1992, Leonard et al. 1994) and how it is bedded (O'Connell et al. 1992, Keys et al. 1976) were also found to affect lying behaviour. Phillips and Schofield (1994) and Singh et al. (1993) showed that cows lay for longer when housed in straw yards than when housed in cubicles. They also showed that cows in oestrus spent less time lying than non-oestrus cows. Lameness also affects lying behaviour; lame cows lay for longer than cows with sound hooves (Singh et al. 1993). Winter (1993) showed that cows in a continuously lit environment lay for less time than cows housed in a 12 hour dark/ 12 hour light environment. Phillips and Schofield (1989) however reported that cows lay for longer when given 18:6 hours light and dark compared to 8:16 light and dark.

6 PREFERENCE TESTING

6.1 Preference Tests and the use of Operant Conditioning

Preference tests allow animals to show preferences for aspects of their environment. Table 1.2 shows the breadth of the subject matter using this method. A comprehensive review of the work carried out at the Ruakura Agricultural Centre Animal Behaviour Unit and some other important work in the field of preference testing and operant conditioning of farm animals is given by Kilgour et al. (1991).

Table 1.2 Research into preferences of farm animals

Species	Stimulus	Researchers
Pigs and Sheep	Temperature and illumination control	Baldwin (1972, 1979)
		Baldwin and Meese (1977)
		Baldwin and Start (1978)
Hens	Lighting preference	Appleby et al. (1983)
	Temperature regulation	Morrison and Curtis (1983)
		Morrison and McMillan (1985)
		Morrison et al. (1987)
		Aslam and Wathes (1991b)
		Hooper and Richards (1991)
	Noise aversion	Nicol et al. (1991)
	Flooring preference	Hughes and Black (1973)
	Spatial preference	Hughes (1975)
	Group size preference	Hughes (1977b)
	Co-joint preference for light and heat	Aslam and Wathes (1991a)
Cattle	Cubicle design preference	Albright et al. (1989b)
		O'Connell et al. (1992)
	Cubicle position preference	Schmisseur et al. (1966)
		Yungblut et al. (1974)
		Keys et al. (1976)
	Bedding preference	Keys et al. (1976)
		Yungblut et al. (1974)
		Hacker et al. (1969)
		O'Connell et al. (1992)
	Housing type preference	Schmisseur et al. (1966)
	Milking machine function preference	Arave et al. (1984)

6.2 Interpretation of Preference Tests

Dawkins (1976) suggested:

> *"To gain insight into the feelings of an animal we need only make one simple assumption about the relationship between the animal's behaviour and what it is actually feeling. This is that situations which act as rewards or positive reinforcers are pleasant to the animal while*

those that are punishing or negatively reinforcing are distressful to it. If this plausible assumption is made, then we can effectively ask an animal what situations are distressful to it by finding out whether they act as positive or negative reinforcers."

This is not to say, however, that animals necessarily know what will contribute to their long term fitness (Duncan 1977). Hughes (1977a) suggested that `wisdom' may be learned, while Duncan (1978) suggested that the process of domestication necessarily produced animals who are less neophobic than their wild counterparts. In this case, when neophobia contributes to fitness wild animals will perform better than domesticated ones (Rooijen 1982). Ainslie (1975) suggested that animals (particularly humans) may;

"Choose the poorer, smaller or more disastrous of two alternatives when they seem entirely familiar with the alternative"

going on to suggest that, although knowing the implications of the alternatives, short term gains may be pursued at the expense of the long term.

There is good evidence to suggest that in the main, animals do behave in ways that maintain or improve their fitness; the fact that animals survive in the wild is an obvious indication of this.

Domesticated animals also show `nutritional wisdom'. Rose and Kyriazakis (1991) reviewed the literature regarding nutritional wisdom in pigs and poultry. They showed that pigs chose a `sensible' diet from seven feedstuffs and hens from nine feedstuffs. Metabolic state may influence the foods chosen, fat pigs chose a different diet to thin pigs. Hens also increased their protein and calcium intake just before laying. The animals needed to be taught the nutritional consequences of eating certain diets however, suggesting that nutritional wisdom is in some way learned. In proof of this, Key and MacIver (1980) showed that Clun lambs (lowland sheep breed) fostered onto Welsh Mountain mothers (hill sheep) and vice-versa had the nutritional preferences of their fostered mothers and not their genetic mothers. Thorhallsdottir et al. (1987) showed that orphan lambs were less neophobic after ingesting poisoned food than lambs with mothers present, again this suggests nutritional wisdom is, to some degree, a learned behaviour.

The implications of this are that farm animals may have a reduced ability to choose wisely, not because they are genetically different from their wild counterparts, but because their social learning has been impaired.

Other factors influencing the interpretation of preference tests include results which show apparent preferences but where no work was involved. With preference tests the absolute strengths of motivation cannot be assessed and only qualitative statements can be made. Operant conditioning offers a method of assessing absolute strength of motivation (Walker 1987) by making animals work. These tests often use `elasticities of demand' to determine the strength of motivation. In essence, the method measures the change in response as the cost of responding increases (Dawkins 1983). A formalised critique of this method is given in Dawkins (1990).

7 ANIMAL LEARNING

Thorpe (quoted in Manning 1979) suggested that there are six ways of classifying learning; habituation, conditioned reflex, trial and error, latent, insight and imprinting.

Habituation is defined as;

> *`the waning of a response, which could still be shown, to a repeated stimulus'* (Manning 1979)

An example of which could be the reduction in fear response of sheep grazing in a field next to a road. The first vehicle to pass down the road may elicit a strong fear response but for subsequent vehicles the response is weakened (Fraser and Broom 1991). Conditioned reflex learning is often called classical conditioning. In perhaps the best known example of classical conditioning, Pavlov (quoted in Manning 1979) trained dogs to salivate in response to a bell ring. Previously the bell had been rung just prior to the presentation of food. Trial and error learning is often called instrumental or operant conditioning. In this the animal learns that making some response elicits some reward, for example pressing a lever, the action of which is rewarded. Latent learning is where animals learn, for example, the location of food even when they are not hungry. Insight learning can be described as;

> *`the apprehension of relationships between stimuli or events'* (McFarland 1989).

Finally, Imprinting can be defined as;

> *`1) Rapid and relatively stable learning taking place in early life, 2)*

The infantile parameter whereby, often without any apparent immediate reinforcement, broad supra-individual characteristics of the species come to be recognised' (Fraser and Broom 1991)

In classical conditioning it is useful define some terminology regarding the stimulus and response. Take the case of Pavlov's dogs salivating at the sound of a bell. The unconditioned stimulus (UCS) is the presentation of food, the conditioning stimulus (CS) is the sound of the bell. The unconditioned response (UCR) is the initial salivation on presentation of food, which then becomes a conditioned response (CR) on the sound of the bell.

The difference between classical and operant conditioning is that with classical conditioning there is a contingency arranged between a stimulus and an outcome. In operant conditioning there is a contingency arranged between a response and an outcome (McFarland 1989). Nicol (1996) suggests that most of an animal's behaviour, including apparently complex behaviour, can be described in simple associative learning terms without recourse to descriptions involving higher cognitive functioning.

There are a number of factors that influence the efficiency with which a CR is trained. Pavlov (Quoted in Manning 1979) showed that the timing of the CS (bell) and the UCS (food) is critical. When the CS was presented at the end of, or after, the UCS the dogs failed to associate the two. Breland and Breland (1961) suggest that, in operant conditioning, the type of task that the animal performs must be related in some way to the behaviour that the animal would normally perform to access the reward. For example, operant devices that reward with food should be operated with, for example, a bird's beak or a pig's snout. While this seems intuitively correct, there are cases where the association between the behavioural response and the reward type is difficult to discern. For example, Baldwin (1978) trained sheep to break a light beam with their muzzles to activate infrared heaters. The nature of the reward is also critical. Reinforcers change the frequency with which a behaviour is performed and occur as negative (unpleasant) or positive (pleasant) reinforcers. Negative reinforcers reduce, whereas positive reinforcers increase, the frequency of responding (Lattal 1991). If a negative reinforcer is particularly unpleasant, the animal may exhibit `one trial avoidance learning', where only one exposure to the reinforcer is enough to prevent the animal from performing the response again (Baron 1991). Finally, repetition is important in establishing an operant task. Training animals to respond operantly often uses a process called `shaping' whereby an animal is initially rewarded simply for going near the operant device. The reward is then given only when, for example, the animal touches the device. This continues until the animal eventually has to perform the operant task to access the reward (Gleeson 1991).

An alternative to using the simple presentation of a single CS to generate a response is chaining. Chaining is a process whereby an animal learns to perform a series of tasks which are rewarded after the completion of the final task. This is the mechanism by which animals learn the locations of rewards in mazes. Whether the animal has a representation of the reward at the start of the maze test or is simply responding to a chain of associations is not clear (Nicol 1996). An elaboration of this process is second order conditioning. Under this process a novel stimulus is paired with a familiar stimulus to which the animal is already trained. With time the animal may learn to associate the novel stimulus with the reward in the absence of the familiar stimulus (Walker 1987). One potential benefit of this process is that it may be possible to train animals to recognise abstract signals by gradually building up the complexity of the signal. For example, in training an animal to recognise an abstract visual signal in a maze that indicates food, the animal could be trained to recognise a simple signal initially (e.g. a bucket; the familiar stimulus), followed by the abstract signal (e.g. different coloured lights; the novel stimulus). With time the coloured lights may become associated with the reward in the absence of the familiar stimulus.

7.1 Types of stimuli

The ability of animals to recognise different images is intuitively obvious, it has also been shown empirically. Kendrick (1990) showed that the cells of the temporal cortex of sheep could be stimulated to `fire' when the image of a sheep with horns was placed in front of them, but not when the image of a sheep with no horns was presented. Similarly, human posture and direction of travel had differential effects on the firing rates of these cells. An image of a figure moving towards the sheep elicited a higher firing rate than a figure moving away.

Of the five senses, the two which have been most intensively studied have been sight and hearing. Heffner and Heffner (1983) have shown that cattle have acute hearing especially at low frequencies. Albright et al. (1966) trained individual cattle to present themselves at a feed trough for a food reward when a tape recorder strapped to their necks emitted a sound. Albright et al. (1992) also trained some cattle to enter a milking parlour when an individual name was called out by an experimenter. Kiley-Worthington and Savage (1978) trained cows to move from pasture to a milking parlour when a car horn was sounded in the field.

In choice experiments, however, this type of acoustic approach may lead to confusion (Baldwin 1992) since sound radiates out in all directions from a source and may be difficult to localise. Here experiments using sight as the medium of communication may be preferable. Indeed, in an operant experiment Uetake and Kudo (1994) found that cows learned to access food quicker when they were given visual as opposed to auditory signals.

The ability of cattle to see colour and their visual acuity has been well characterised. Gilbert and Arave (1986) showed that Holstein cows have good colour vision although at short wavelengths (greens and blues) they cannot differentiate between two colours competently. Riol (1989) presented similar results for Spanish Fighting cattle which showed that at wavelengths of 500-400nm these cattle could not distinguish between a colour and a grey board of approximately equivalent luminosity. Phillips and Weiguo (1991) found that cattle have a lesser ability to discriminate between light and dark than humans. Entsu et al. (1992) showed that visual acuity in cattle is good, although variable, but is not as good as human vision. Baldwin (1981) showed that sheep and calves could distinguish between different shapes to obtain a food reward even when the differences were quite subtle.

As an added attraction to static colour choices, flashing lights could be used. Lewis and Hurnik (1979) attracted more turkey poults to a feeder using flashing lights in the feeder than a conventional feeder and they ate more food (lack of feeding in newly hatched poults is responsible for high mortality). Baldwin (1992) suggested that flashing coloured lights may be useful in stimulating cattle to learn the correct response in mazes because they may be visually interesting and memorable.

7.2 Intelligence and discrimination problems

Kilgour (1987) scored various species on their ability to solve and repeat a maze problems. Children scored 99%, pigs, cows, goats and dogs scored a similar 90-93%, rats and cats scored 81% and mice and guinea pigs scored 48-53%. These data show that farm animals can learn at least as well as dogs, who are generally regarded as highly trainable. However, the use of these tests to suggest causes of behaviour (or motivations for behaviour) has been criticised by Fraser (1978) who suggested that;

> *"Noetic behaviour* (that concerned with intelligence) *is apparently a supportive one in sentient behaviour".*

This means the anthropomorphic view that intelligence largely influences behaviour is presumptive when applied to animals. Nicol (1996) contended that cross-species comparisons of learning ability are often meaningless since animals are adapted to occupy different ecological niches.

Work with calves has shown that they can learn to discriminate between buckets of different size and tone (black or white) (Schaeffer and Sikes 1971, Wieckert et al. 1966). In a simple maze test Kovalcik and Kovalcik (1986) showed heifers (yet to have their first calf) learned quicker than primiparas who learned quicker than second lactation cows. When the experiment was repeated after six weeks however, the cows performed better than the heifers. Grambling et al. (1970) suggested a similar result regarding the learning ability of calves aged between two and six months old. They also suggested that learning ability may be heritable, a view supported by the work of Arave et al. (1992a) who also showed that sex had an effect; heifer calves learned how to solve a maze problem quicker than bull calves.

7.3 Using mazes to test learning and preferences

Mazes have been used extensively to study aspects of learning. Psychologists used various types of mazes to study how rats learned tasks (e.g. Spence and Lippitt 1948, Tolman 1951, Fehrer 1951, Restle 1957). Other more recent maze studies have looked at learning and memory more widely, studying horses (Marinier and Alexander 1994, Kratzer et al. 1977, Fiske and Potter 1979, Warren and Warren 1962), chicks (Warren and Warren 1962), fish (Warren 1960), racoons (Warren and Warren 1962) and cattle (Kilgour 1981, Schaeffer and Sikes 1971, Stewart et al. 1992, Arave et al. 1992b, Kovalcik and Kovalcik 1986, Grambling et al. 1970, Wieckert et al. 1966, Arave et al. 1992a). Recently, mazes have been used to study preferences of farm animals for different treatments and to study farm animals' sensory perception. Some of these are shown in table 1.3

Table 1.3 Use of mazes to study preferences and perception

Farm animal species	Purpose of study	Researchers
Cattle	Brightness discrimination	Phillips and Weiguo (1991)
	Colour perception	Riol et al. (1989)
	Visual Acuity	Entsu et al. (1992)
	Aversion to a crush	Grandin et al. (1994)
	Understanding spatial memory	Bailey et al. (1974)
Sheep	Handling preferences	Rushen (1986)
	Restraint preferences	Grandin et al. (1986)
Deer	Handling preferences	Pollard et al. (1994)

All of these studies have used Y-mazes (except Bailey et al. 1974). Essentially, these consist of an entry area, opening into a decision area and from there into one of two spurs. The treatments are located in either spur. Y-mazes provide a good environment for testing preferences since the treatments can be in similar environments in either spur, reducing the chance that an animal may choose a particular treatment because of the treatment's location, rather than the properties it possesses.

There are two experimental designs used here. In the perception tests (Phillips and Weiguo 1991, Riol et al. 1989, Entsu et al. 1992) the animals were trained to use visual signals to find a food reward randomly located down either spur. If they learned to find the food, they were deemed to be able to visualise differences in the signals. If the animals did not learn they were deemed to have not understood the signal, presumably because they could not detect differences between the two signals. By narrowing the difference between the two signals the limit of the animal's perception could be reliably inferred. This general method is an example of stimulus control (Harrison 1991). The general experimental design is one of concurrent scheduling, in that each signal is notionally reinforced under different reinforcement schedules, i.e. choosing the `wrong' schedule is never reinforced and choosing the `correct' signal is always reinforced. An alternative to the concurrent method is the successive method. Here the animal is presented with one of a number of stimuli individually and is trained to respond in the presence of one of these signals but not the other(s). Concurrent schedules have the advantage of allowing animals to compare differences between signals more closely since they are presented together.

The choices made by animals when given concurrent choices can be modelled using the matching law (Williams 1994). Essentially, this dictates that the proportion of responses to two or more stimuli are directly related to the reward value generated by the response. For example, in a Y-maze with food randomly located in either spur and indicated by a signal there are two potential rewards, that of using the preferred spur and that of choosing the food containing spur. Presuming the animal perfectly associates the signal with the food reward then the proportion of choices to the preferred spur compared to the food containing spur is a measure of the relative rewarding values of each.

The other tests shown in table 1.2 (except Bailey et al. 1974) use a method whereby each treatment is located repeatedly down one or other spur and the animal chooses between each treatment in either spur.

Some researchers have shown that animals have initial preferences for using one or other spur, independent of the treatment (Pollard et al. 1994, Grandin et al. 1994, Rushen 1986). Grandin et al. (1994) suggested that this phenomenon would be more evident when the treatments are similarly motivating. Presumably the difference in motivation for choosing one or other treatment would be less than the motivation to use a particular spur (in agreement with the matching law). In cattle `handedness' has been well observed. Cows are known to prefer certain sides of a parlour (Albright et al. 1992), and on which side they lie in cubicles; although this is also closely related to stage of pregnancy and the slope of the floor (Albright et al. 1989a, Albright et al. 1989b, Yungblut et al. 1974). Certain factors may affect the handedness of cattle, for example the type of housing (Arave et al. 1992b), or the spin direction and number of hair whorls on the cow's forehead (Tanner et al. 1994).

8 OBJECTIVES AND STUDIES PERFORMED

The first three experimental chapters in this thesis dealt with methods used to train cows to recognise visual signals that indicated randomly presented foods in either spur of a specially constructed Y-maze. The aim of this was to find a signal which could reliably inform the cows of the location of other treatments, such as milking, in the maze. Randomly swopping these treatments may have helped prevent the development, or at least allowed detection of, a cow choosing a particular spur for reasons other than the treatment it contained (for example because they preferred turning left to turning right, Grandin et al. 1994). The first of these three chapters (chapter 3) detailed attempts to train cows to understand visual signals with one food reward. Chapter 4 detailed the results of an investigation into food preferences. Chapter 5 was similar to chapter 3 but used the findings of chapter 4 to provide four highly preferred foods as the reward.

Chapter 6 investigated motivation to be milked and how that was affected by stage of lactation. These experiments were important since this may be one of the motivations that affect how cows attend the AMS. If cows did choose to be milked then this would be another welfare benefit to automatic milking.

In these experiments cows were given the choice to be milked every $3^1/_2$ hours, this allowed some assessment of the relative importance of the physical (e.g udder weight, pressure or size) (Phillips 1993, Rathore 1982), and psychological factors involved in motivation to be milked, since cows that chose to be milked at every opportunity would presumably have little physical stimulus due to milk pressure in the udder. In addition, motivation to eat concentrate was compared with motivation to be milked to assess the relative motivations to eat and be milked.

The remaining chapters dealt with automatic milking and were designed to understand the factors affecting attendance at, and behaviour in, the AMS. These experiments principally dealt with the effect of food type and location on the interaction of the cows with the AMS.

Chapter 7 detailed a novel method by which dominance rank and fearfulness were determined for a small group of cows. These cows were then used in AMS trials.

Chapter 8 studied the effect of feeding forage or concentrate in the exit area of the AMS (i.e. the cows had to visit the AMS to access these foods under an operator control type design), and feeding or not feeding concentrate while the cows were being milked. The frequency, pattern and order of attendance were considered along with the effects of rank, fearfulness and age. The aim of this experiment was to assess the relative merits of feeding concentrate as opposed to forage in the exit area with a view to using concentrate in future applications. This would remove the modified feeding behaviour associated with feeding forage in the exit area (Ketelaar-de-Lauwere 1992, Winter 1993).

Chapter 9 studied the effect of these feeding regimes on the cow's speed of movement through the system; rate of throughput of cows is a major factor in the efficiency of the system. Feeding methods which slow cows through the system would be unlikely to be implemented.

Chapter 10 studied the effect of feeding or not feeding in the milking stall on the behaviour of the cows while they had their teat cups attached and were being milked. This chapter tested the suggestions on the sorts of behaviour that may be exhibited when cows are or are not fed, for example whether the cows exhibit more restless behaviour when fed than when not fed (Whipp 1992). It was also try to replicate the findings of Svennersten and other researchers (Svennersten and Samuelsson 1992, Svennersten and Samuelsson 1993, Svennersten et al. 1995), who showed that feeding the cows while they are being milked increased some milking parameters such as yield.

Chapter 11 was a linking chapter which looked at the effect of providing or not providing a food reward in the AMS, on attendance. This experiment assessed whether the results found in the milking motivation chapter (6) were applicable to automatic milking and gave an indication of the relative effects of motivation to be milked or to access food in the cow's overall attendance to the AMS.

CHAPTER 2

MATERIALS AND METHODS

1 Location and cows

All the experiments reported in this thesis were performed at Cheseridge Dairy Farm, belonging to the Institute for Animal Health, Compton, Berkshire.

The farm had approximately 200 Holstein-Friesian dairy cows calving all year round and was run commercially. Cows were, however, available for experimentation by various projects within the institute. The mean yield was 6,200l, and the breeding policy was to increase milk yield and protein and improve hooves and legs. The cows were housed in cubicles, and split between two sheds according to their stage of lactation. The cows were normally milked through a 16:16 herringbone parlour. The morning milking started at 05:30 and the afternoon milking started at 15:30. For independent trials cows could be milked through a three-stall tandem parlour, or an automatic milking system, in other buildings.

The cows were fed a complete ration *ad lib*. This comprised grass silage (36% fresh weight (FW)), whole crop cereal (16% FW), maize silage (46% FW) and straw (2% FW). This diet had a metabolisable energy value of 11.5MJ/kg of dry matter and a crude protein level of 18.3% of dry matter. This ration was supplemented by a commercial dairy cow cake (BOCM/Pauls dairy 1592 cake) fed according to yield which was dispensed from automatic concentrate feeders. During the summer the cows were allowed onto the farm's pasture land to graze.

2 The Maze

To study motivation and learning a Y-maze was built. The experimental area had facilities to house six cows in cubicles, a feed barrier, two drinkers and access to a small concrete yard at one end. Another part of the building housed the three-stall tandem parlour mentioned earlier.

The maze was 9m long, the sides 1.8-2.0m high and the passageways 1m wide. The floor was concrete, sloping gently upwards towards the end of the maze. The sides were constructed from 18mm plywood attached to 60mm diameter upright sections of pipe bolted to the floor. The whole structure was braced by smaller gauge pipe connecting the uprights above head height. The maze is shown diagrammatically in figure 2.1a and photographically in figure 2.1b

The maze consisted of a holding stall, a decision area and two spurs, each separated by doors. The entrance to the holding stall had a strong side hinged gate designed to hold cows and prevent them from reversing out. The exit of the holding stall was via one-way full-length double doors. The doors opened into the decision area when a latch was remotely operated. The opposite end of the decision area had two exits, one into each of the left and right spurs. Two one-way double doors could be fitted into these exits if necessary. These were screened with black plastic to prevent the cows from seeing through them and weighted so the cow had to push to get through; they also closed immediately the cow moved through them. In initial experiments single horizontal bars at the ends of the spurs could be raised to allow the cows to exit the maze. In later experiments these bars were replaced with more substantial wooden doors. Once the cows had been through the maze they could return to the living area via a return race running down one side of the maze.

During experiments the cows were herded into a collection ring made from movable gates. This allowed cows that had completed a trial to be separated from cows who had not. When the maze was not in use, the collection ring could be folded back. This arrangement is shown in figures 2.1c and 2.1d.

The maze was semi-rigid, strong enough to be a deterrent to misbehaviour but not so strong that a determined or panicked cow would injure herself, or the maze, if trying to escape.

Figure 2.1a: Plan view of Y-maze

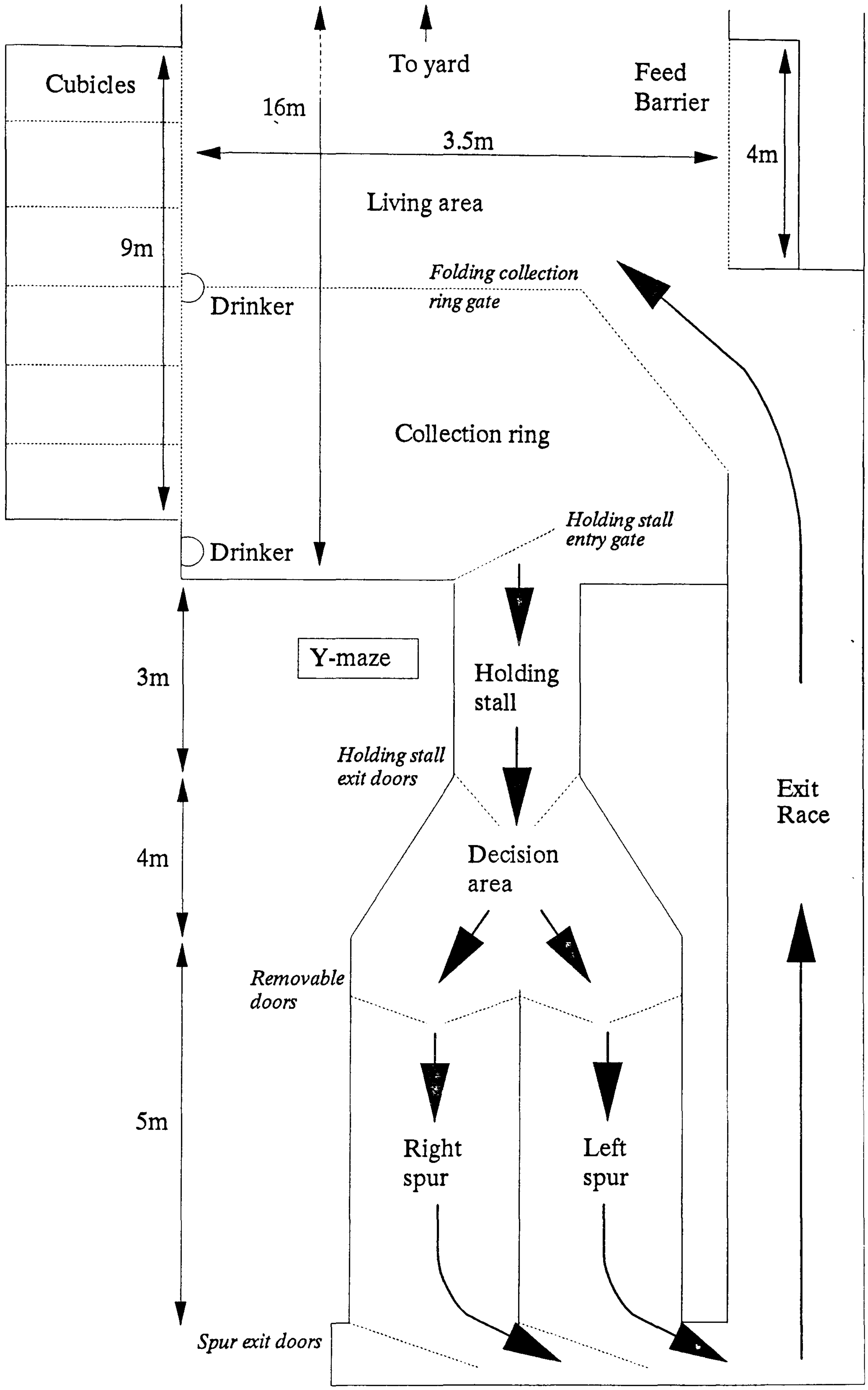


Figure 2.1b: Photograph of Y-maze looking from the holding stall end

Figure 2.1c: Photograph showing collection ring

Figure 2.1d: Photograph showing collection ring folded back

3 The Experimental Automatic Milking System (AMS)

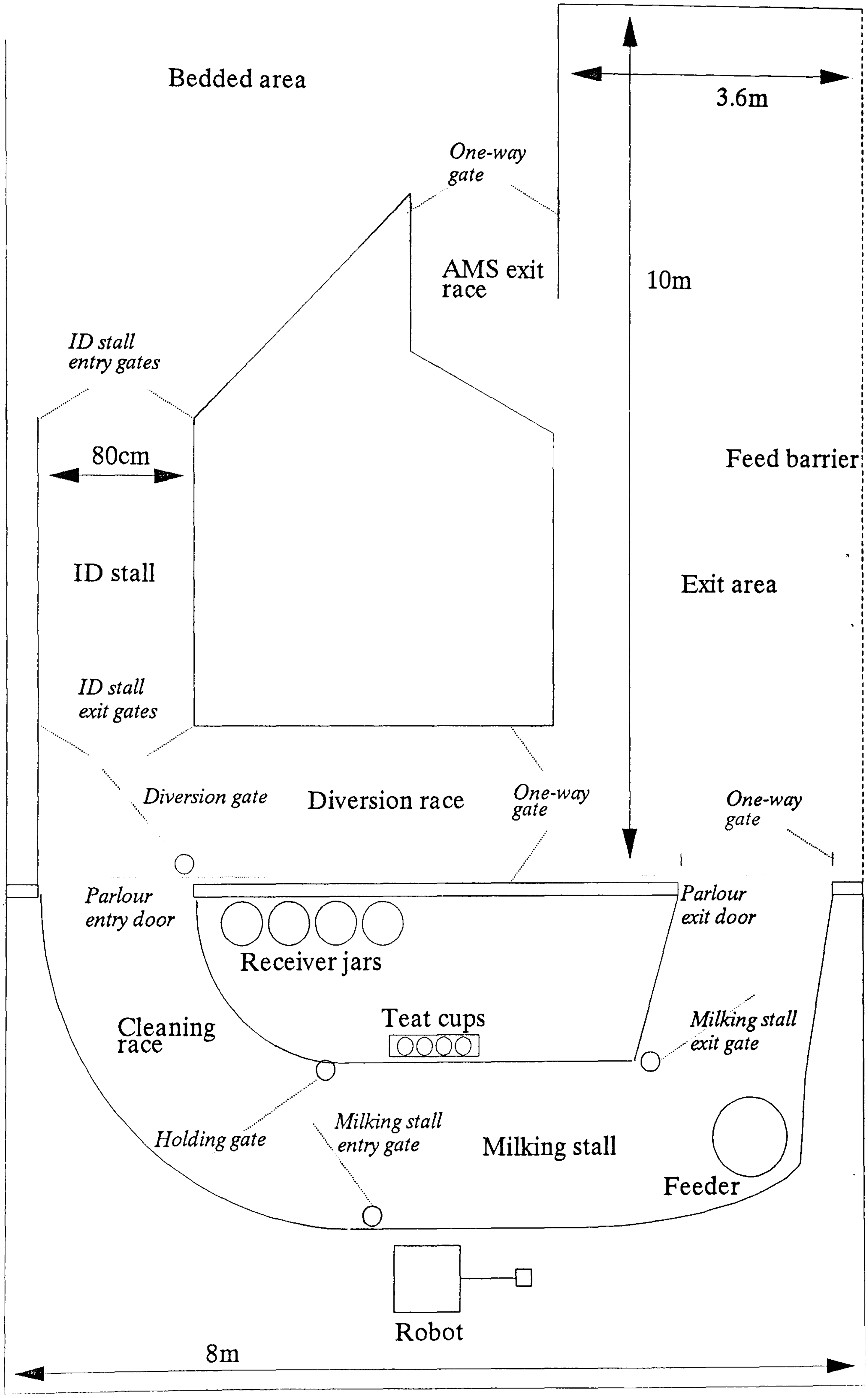
3.1 The AMS

The AMS was located at Cheseridge farm and was housed in a clear span barn which also contained young and dry stock at various times. The AMS facility was designed to test elements of automatic milking. It was not designed to be a full specification automatic milking system. The description given here is one possible design for the system that remained constant during this thesis.

Variations from the design described here are detailed in the materials and methods sections of individual experiments. If no variations are described, the system worked as detailed here. In this thesis the AMS had two main parts, an outside concreted area and an enclosed parlour into which the cows entered when they were milked. When a cow entered the system, she was made to use one of two routes. In the first she was not milked and moved directly from the identification (ID) stall into the exit area, completely bypassing the milking parlour, via the diversion race. The second was from the ID stall into the milking parlour and then into the exit area. These two routes and a plan of the AMS are shown in figure 2.2a.

The cow entered the AMS from the bedded area by entering the ID stall. This was a stall with pairs of gates at either end. When ready to receive a cow the entry gates were open and the exit gates closed. An antenna in the stall connected to a computer read the cow's ID from a transponder worn around her neck. Once the cow's ID had been read the entry gates closed (if the cow's ID was not read, for whatever reason, the entry gates did not close). The computer-based management system then decided whether the cow needed to be milked. This was based on the interval since the cow was last milked. Any interval required could be programmed into the management system. If the management system decided that the cow did not need to be milked the diversion gate swung across the entrance to the parlour. When the ID stall exit gate opened the only option the cow had was to use the diversion race, enabling her to walk directly into the exit area without going through the parlour. If the cow was selected to be milked, the diversion gate swung to block the entrance into the diversion race and the cow had no option but to continue into the milking parlour. The progress of the cows through the system was at their own volition. No mechanical devices were used to encourage them through any part of the system. Photographs of a cow entering

Figure 2.2a: Plan view of the automatic milking system



the milking parlour and diversion race from the ID stall are shown in figures 2.2 b and c.

Before the cow reached the milking stall, she was held at a manually operated holding gate where her teats were cleaned by hand. Once they were clean the holding gate opened and the cow entered the milking stall. The milking stall entry gate then closed behind her.

In the milking stall the cow stood with her front feet on a low platform (100mm high). In this position the cow's udder swung forward which allowed good access for the attachment robot (Mottram 1992). At the head of the stall there was a concentrate feeder which could move forward and backwards. This operated to ensure that no matter what length the cow, her udder was always positioned optimally for attachment. The teat cups and milk collection equipment were located to the left and rear of the cow. The attachment robot was bolted to the floor to the right and rear of the cow.

The robot was pneumatically actuated and compliant. If the cow struck it, it would deflect preventing damage to the cow or the robot. A single arm attached the teat cups in turn, each picked from the holder on the left side of the cow. Teat location was a two-stage process, dead reckoning from the stored positions on the database and local sensing. Initially dead reckoning returned the robot to the position of the teats programmed in during a manual teat location training procedure. Local sensing then took over, using a small open ended box, 80mm x 80mm, at the end of the robot arm containing an array of infrared light beams. If the teat was now inside this box, the pattern of beam obstruction allowed the box to centre the teat within itself and over the open end of the teat cup which was then attached. If the teat was not found the arm returned to the initial programmed teat position and re-tried. If that failed the robot gave-up, dropped the teat cup onto the floor of the milking stall and continued attaching the remaining teat cups.

The individual teat cups were removed automatically once each quarter of the udder had been milked out. Once they had all been removed, the sliding parlour exit door opened followed by the milking stall exit door. The feeder then retracted and the cow was free to leave the parlour. On stepping through the parlour exit door the cow's teats were sprayed automatically with a proprietary teat dip.

Figure 2.2b: Cow entering the milking stall from the ID stall

Figure 2.2c: Cow entering the diversion race from the ID stall

The milking stall and the bypass race led into the exit area, a small concrete yard, on one side of which was a permanent feed barrier and on the other, a one way race leading back into the bedded area.

The races and stalls within the AMS were made of galvanised steel pipe held together with clamps. This allowed the system to be modified as an experiment required. The gates were controlled pneumatically and all would `give' if a cow were to push hard against them. The races had spring-loaded one-way gates placed along them to prevent cows moving the wrong way through the system. The position of the cow within the AMS was determined by her breaking light beams which crossed the races. These produced signals which the computer control system used to open and close the various gates in the correct sequence.

A detailed description of the system's hardware can be found in Street et al. (1992) and Frost et al. (1993). The management system is described in Spencer and Street (1992). A report on the operation of the AMS in field trials can be found in Allen et al. (1992) and Mottram et al. (1992).

3.2 Feeding

In the AMS the cows could be fed concentrate manually from a feeder in the milking stall. The cows could also be fed forage in the exit area from a feed barrier 5m long with twelve slots separated by diagonal dividers. The cows could be fed similarly in the bedded area behind a continuation of this barrier. The forage was normally delivered by a forage wagon between 06:00 and 07:00.

3.3 The bedded area

The bedded area was of variable length depending on the number of animals being used on the experiment. The cows were loose housed and the area was re-bedded as needed, generally every other or third day, with either barley or wheat straw. The bedded area also contained two water troughs. At night the area was lit by two low pressure sodium lights. Additional lighting for video recording purposes was available from three floodlights variously located.

4 Statistical analyses

The experiments described in this thesis were analysed using both parametric and non-parametric statistics. Often the decision to use analysis of variance over non-parametric tests was clear, for example when analysing the time budget data presented in chapters 8 and 9. In other cases non-parametric analysis was the only option, for example when comparing the consistency of three or more rank orders, Kendall's Coefficient of Concordance is the most appropriate analysis.

Where the data was in the form of a discrete variable, the decision was more complicated. This is highlighted in chapter 8 where the number of visits to the automatic milking system was analysed according to two treatments, feeding or not feeding in the milking stall and feeding forage or concentrate in the exit area. Two data sets from this chapter illustrate the different decisions which were made when choosing whether to use parametric or non-parametric analyses. Table 2.1 shows a data set for 14 cows.

Table 2.1 Data set 1: Effect of parlour and exit feeding on attendance by individual cows during three periods

	Period 1 T1	Period 2 T2	Period 3 T1
Cow 1	15 F	5 NF	15 F
2	12 NF	10 F	11 NF
3	26 F	12 NF	26 F
4	13 NF	10 F	14 NF
5	21 NF	29 F	23 NF
6	2 F	3 NF	3 F
7	15 NF	12 F	17 NF
8	20 F	5 NF	15 F
9	30 NF	21 F	32 NF
10	27 F	11 NF	23 F
11	27 NF	28 F	24 NF
12	12 F	7 NF	15 F
13	17 NF	15 F	18 NF
14	16 F	4 NF	13 F

(Where F= fed in the parlour, NF= not fed in the parlour, T1= forage fed in the AMS exit area, T2= concentrate fed in the exit area)

Since these data were extensive and normally distributed, they were analysed using analysis of variance with F/NF and T1/T2 as the treatments, and blocked by individual animals nested within periods. While the data were not of a continuous variable type (i.e. there can be no fractions of visits), the analysis treated the data as if it were. Consequently, when the analysis of variance suggested that the main effect of feeding forage in the exit area was to give an attendance rate of 17.9 visits per cow over three days, we know that detail, which did not exist in the raw data, had been added since there cannot be fractions of attendances. If the data set is sufficiently large, however, and normally distributed, this analysis is still stronger and more descriptive than a corresponding non-parametric analysis.

Table 2.2 shows a second data set. Here are only eight cows and another factor were taken into account, that of fearfulness. Four cows are classed as fearful and four as bold.

Table 2.2 Data set 2: Effect of fearfulness and parlour and exit feeding on attendance rates by individual cows over three days

Cow	Fearful/Bold	Period 1	Period 2	Period 3
1	Fearful	15 F	5 NF	15 F
2	Fearful	13 NF	10 F	14 NF
3	Fearful	20 F	5 NF	15 F
4	Fearful	16 F	4 NF	13 F
5	Bold	12 NF	10 F	11 NF
6	Bold	21 NF	29 F	23 NF
7	Bold	27 NF	28 F	24 NF
8	Bold	17 NF	15 F	18 NF

If analysis of variance were used here, the treatment structure would be the effect of F/NF, T1/T2 and Fearful/Bold on attendance. As there are only 24 data points split between three treatments, however, the analysis would be in danger of significantly adding information to the analysis. In addition the presumption that the data conforms to a normal distribution cannot be justified on such a small data set. Here the analysis was performed using the non-parametric Mann-Whitney U test and the Wilcoxon matched pairs test.

The decision to use parametric or non-parametric analyses was also made in those analyses which used linear regression. In all cases in this thesis the decision was taken that regression analysis would only be used for visual representations of trends since none of the analyses used a continuous variable on either axis. An example of this policy is shown in chapter 4 table 4.6 where the preferences for certain foods were ranked over 15 trials. In figure 4.3 a pictorial representation is shown of the change in ranked preference for two feeds over the 15 trials. The level of significance for each of these data sets was calculated using the Spearman's rank test since neither trial number nor summed rank is a continuous variable.

When using analysis of variance the data were checked to determine if they approximated to a normal distribution. This was done by plotting the residual values from the analysis (i.e. the difference between the observed and fitted values) against the fitted values from the analysis. If data were normally distributed the scatter of the residual values data would be random along the fitted value axis. If not, the scatter of the residual values would change in magnitude along the fitted value axis. The graphs were inspected by eye and if the data appeared not to be normally distributed they were transformed by calculating their natural logarithms and again checked for normal distribution.

The statistical procedures used in this thesis are explained and examples given in the following references;

Analysis of Variance- Hays (1994) pp 597-672

Regression Analysis- Hays (1994) pp 376-596

Chi-Square Test- Siegel (1974) pp 42-47 and pp 104-111

Spearman's Rank Test- Siegel (1974) pp 204-213

Kendall's Coefficient of Concordance- Siegel (1974) pp 232-237

Mann-Whitney U Test- Siegel (1974) pp 116-127

Wilcoxon Matched Pairs Test- Siegel (1974) pp75-83.

CHAPTER 3

THE RESPONSE OF DAIRY COWS TO VISUAL SIGNALS INDICATING THE LOCATION OF FOOD IN A Y-MAZE

1 Introduction

A Y-maze (such as that described in chapter 2) can be used to test preferences, since many incidental factors that may affect the choice between treatments are removed. Without a maze an animal may choose a particular treatment because the location of that treatment is lighter or darker, warmer or cooler than another treatment. Alternatively, the surrounding environment of one treatment may be more interesting or less threatening than another. A Y-maze allows the experimenter to define closely an environment where two treatment locations can have similar physical characteristics. This reduces the motivation of an animal to choose a particular treatment for reasons other than the properties of that treatment. Y-mazes have been used extensively to assess the learning ability of cattle (e.g. Kilgour 1981, Wieckert et al. 1966, Schaeffer and Sikes 1971, Grambling et al. 1970, Kovalcik and Kovalcik 1986, Arave et al. 1992b, Stewart et al. 1992, Arave et al. 1992a).

In a Y-maze an animal may still prefer a particular spur irrespective of the treatment which it contains. Cows are known to prefer certain sides of parlours (Albright et al. 1992), and Tanner et al. (1994) have suggested that laterality in the parlour may be related to the `spin' direction and number of hair whorls on a cow's forehead. Arave et al. (1992b) suggested that the type of calf housing affected the lateral choices of calves in a maze. Cows also prefer which side they lie on when in cubicles (Albright et al. 1989a, Albright et al. 1989b, Yungblut et al. 1974), although this is closely related to the slope of the floor and stage of pregnancy.

In a Y-maze a lateral tendency may be generated or reinforced if, during training or experimentation, a cow constantly finds a positively reinforcing treatment located in a particular spur. Grandin et al. (1994) showed that in a Y-maze, with being held in a cattle-crush as the treatment in one side and no treatment in the other, the cows initially chose the no treatment side. When the treatments were swopped between the two spurs however, some cows continued to choose the same spur although it resulted in being held in the crush.

One way to account for a preference of this sort is to swop randomly the treatments between the two spurs. This might prevent the generation of strong laterality preferences and highlight existing ones. This design however, requires that the cows are given some unambiguous signal as to the nature of the treatment located in either spur. This signal should fulfil a number of criteria of which four of the most important may be; 1) It must not affect the animal's choice in itself, i.e. it must not be attractive or threatening. 2) The cows must be able to perceive it. 3) It must be easily and quickly learned by a high proportion of all cows since it is only a tool for a preference test. 4) It must be demonstrably unambiguous in operation.

Three classes of signals could be used; olfactory, auditory and visual. The operation of an experiment using olfactory or auditory signals would be problematic if they were to be demonstrably unambiguous. For example, cows probably have a greater ability to recognise olfactory signals than man and as such it would be difficult to ensure, while swopping the signal between the spurs, that no trace of either signal was left in the previous spur, or that breezes and draughts did not disperse the signal. Auditory signals would also be difficult to use in a Y-maze, as they are difficult to localise; sound radiates out in all directions from the source. Of the three classes, visual signals are the easiest to use by the experimenter since humans have better visual capabilities in terms of acuity (Entsu et al. 1992), ability to distinguish light and dark (Phillips and Weiguo 1991) and recognise colour (Riol et al. 1989, Gilbert and Arave 1986), than cows. Cows can discriminate shapes well (Entsu et al. 1992, Baldwin 1981) providing the environmental light level is high. At lower light levels the ability of cattle to discriminate effectively declines faster than for humans (Phillips 1993). Cows can also perceive the longer wavelength colours (red, oranges and yellows) (Riol et al. 1989, Gilbert and Arave 1986). Clearly, visual signals can be demonstrably unambiguous merely by observation since humans have superior acuity, colour and low light level vision.

There were two aims of the experiments in this chapter. First to determine if cows could reliably find a food reward in the Y-maze (described in chapter 2), indicated by visual signals. Secondly to build up the apparent complexity of the visual cues until one was found that was abstract enough to be used to indicate the location of any treatment but which still conformed to the four requirements listed above. Four experiments are described here, the first was designed to test if the cows could choose the spur with a bucket containing food which was randomly swopped between the spurs. This was to test if the cows could associate a very simple signal (a bucket) with a food reward. The second experiment built on the complexity of the signal by making the cows choose between two differently coloured buckets only one of which contained food, these buckets again being randomly swopped between the spurs. This was designed to test if the cows could discriminate accurately between colours in the Y-maze and use this information to choose the correct (food bearing) spur. The third experiment used a randomly lit or dark spur as the signal; this was a strong but more abstract signal. The fourth experiment became even more abstract with the cows being given the choice between red and yellow filtered spotlights trained on the decision doors. This is the sort of signal that could be used in preference tests since it conforms to all the criteria given above.

This is the first in a series of three chapters looking at rewards and signalling in the Y-maze. The experiments reported represent a larger series of experiments carried out over nine months.

2 Materials and Methods

2.1 Materials

The Y-maze has been described in detail in chapter 2.

2.2 General method

The experiments were conducted in the Y-maze built at Cheseridge Farm, belonging to the Institute for Animal Health, Compton (see chapter 2). During the day cows were herded into the shed which contained the maze where they had access to cubicles, a small yard (for some of the time) and a feeder containing hay. The cows were assembled from a cubicle house at 09:30, after the morning milking, and returned at 15:30 when they were milked again.

There were three time periods, 09:30-11:00, 11:30-13:00 and 14:00-15:30. In each time period the cows were given two trials each. Occasionally a cow had less than six trials in a day, mostly because of routine pregnancy testing or illness.

For each trial the cows were rounded up into the collecting ring and allowed through the maze individually. They were free to enter the holding stall in any order. Once in the holding stall the cow was held for 60s to allow her to settle. The holding stall exit gate was then remotely opened and the cow was free to enter the decision area and from there whichever spur she wanted. If she chose the spur containing food she was allowed to eat, then encouraged out and returned to the living area via the return race. During the first three experiments, if she did not choose the spur with food, she was manually reversed into the holding stall (by walking towards her from the spur's exit) and made to take the `correct' food spur (by barring the entrance to the `wrong' empty spur). In experiment 4 the protocol was revised and if the cow made a wrong choice she was reversed back along the spur into the holding stall from where she was allowed another try. In all, the cows were allowed three tries before they were guided down the correct spur by the original method.

The food reward was $^1/_3$ kg of either sugar beet pellets (Trident Feeds Ltd.) or the farm's normal pelleted dairy cake (BOCM/Pauls), details of each of these can be found in chapter 4, appendix 4.

The pseudo random location of food in each trial was derived from a series of random numbers (Lindley and Scott, 1990). Any sequence that required the food to be placed three or more times in the same spur was removed to help prevent the cows developing a laterality preference. All experiments used repetitions of the following sequence, where the letter refers to the spur in which the food was placed (L=left and R=right);

LLRRLLRLRLLRLRRLRLLRLRLRLRLLRLRRLRLRLRRLLRRLRLLRLRRLR LRRLRLLR

2.3 The Cows

Three groups of six cows were used during these experiments. The selection criteria were for cows of quiet disposition, with good hooves and in late lactation. Descriptions of the cows are given in table 3.1, where DIM indicates the number of days in milk.

Table 3.1 Description of the animals used

Cow	Group	Parity	DIM (days)	Yield (l)
9595	1	1	230	13.5
C980	1	3	254	14.2
D549	1	2	278	9.8
C506	1	3	253	12.9
9009	1	1	275	8.7
B825	1	2	259	9.1
1004	2	1	230	14.4
1082	2	2	243	14.2
1138	2	1	254	12.3
1035	2	1	210	13.9
1003	2	1	232	15.9
1176	2	2	237	13.9
1130	3	1	254	13.7
0023	3	1	267	12.9
9461	3	1	234	15.7
9054	3	1	252	12.7
2214	3	2	274	13.5
8058	3	3	238	11.4

2.4 Training

The cows were trained to move through the maze individually. Initially they were herded through as a group and then individually. Once they appeared familiar with the operation they were then fed in the maze. The cows rarely needed more than five or six passes through the maze to become familiar with the procedure.

2.5 The treatments

Four experiments are described here, each using different and increasingly complex signals.

2.5.1 Experiment 1

This experiment used the group 1 cows with 9009 and B825 as controls. In this experiment the cows were tested to see if they could associate a large (10 l) grey plastic bucket with food. One spur contained the bucket with $^1/_3$ kg food in it and the other spur contained nothing. Each cow was allowed 60 trials over 11 days. For the first 14 trials the food reward was normal concentrate (NC). One cow would not eat the NC however, so for the remainder of the trial the NC was replaced with sugar beet pellets (SB).

The control cows were only used as such in the first 28 trials, for the first 14 of which they were not fed in the maze. This was to detect any tendency by the cows to choose the same spur as the previous cow. For the next 14 trials, because their passage through the maze had become so slow (presumably through not being fed), the cows were fed in the exit area of the maze with the feed bucket equally visible down either spur. For the remainder of the trial they were trained to associate the bucket with food in readiness for experiment 2.

2.5.2 Experiment 2

This experiment used the group 1 cows with 9009 and B825 as the controls. In this experiment the cows were given the choice between a red and yellow bucket randomly swopped between the two spurs. For each cow one coloured bucket was designated as the food bucket and the other as the empty bucket. The buckets are shown in figure 3.1. The cows and their designated buckets are shown in table 3.2.

Table 3.2 Coloured bucket designation for each cow in experiment 2

Cow	Empty bucket	Food bucket
9595	Yellow	Red
C980	Yellow	Red
D549	Red	Yellow
C506	Red	Yellow
9009	Either	Either
B825	Either	Either

The cows were fed NC and given 30 trials over five days

2.5.3 Experiment 3

This experiment used the group 2 cows. The cows were given the choice between a lit and a darkened spur. During the experiment the shed lights were turned off and the overhead skylights covered. The treatments involved suspending two 1000W spotlights above the decision area and directing one down each spur. The spotlights could be independently controlled, thus, one spur could be brightly lit while the other remained in comparative darkness. Three cows were fed in the lit spur and three in the dark spur as shown in table 3.3.

Table 3.3 Treatments in each spur in experiment 3

Cow	Fed	Not fed
1004	Light	Dark
1082	Light	Dark
1138	Light	Dark
1035	Dark	Light
1003	Dark	Light
1176	Dark	Light

Initially the cows were trialed with only one grey (101) bucket, containing NC in the appropriate spur, to ensure that the cows associated a bucket with food. The cows were given 18 trials on this part. In the second part another `dummy' bucket was introduced into the maze. This bucket had the same quantity of NC as the other bucket but wire mesh was placed just above the level of the food so the cows could not feed from it (shown in figure 3.2). This was to ensure that the cows were not simply finding the food by its smell. During this experiment the cows were each given 30 trials.

Figure 3.1: Red and yellow coloured buckets

Figure 3.2: Large grey buckets, left bucket is the ‘food’ or ‘correct’ bucket, right hand bucket is the ‘dummy’ bucket showing the wire mesh.

2.5.4 Experiment 4

In this experiment the spotlights used in experiment 3 were filtered through red or yellow gel filters. Each spotlight had a pair of these filters so each could produce either red or yellow light. Instead of illuminating the spurs each spotlight illuminated the decision doors of each spur. The doors were painted white and illuminated with the treatment colour. In addition, the lights flashed at a frequency of 1hz, which was designed to highlight the signal in the general environment. The cows from group 3 were used. The experiment was designed so each cow would act as her own control, when she had shown adequate signs of learning, by trialing her with no signals. The treatment designations are shown in table 3.4.

Table 3.4 Treatments in each spur in experiment 4

Cow	Fed	Not Fed
30	Red	Yellow
23	Red	Yellow
61	Red	Yellow
56	Yellow	Red
14	Yellow	Red
58	Yellow	Red

For the first part of the experiment (54 trials/cow) the cows were tested with an empty bucket and a food bucket, in the second part (20 trials/cow) the empty bucket was replaced by the `dummy' bucket.

The cows were trained to push through the decision doors before the experiment started. This was achieved by running the cows through the maze a number of times and each time gradually closing the doors until the cows learned to push through them.

2.6 Analysis

The non-parametric Chi-square test was used to analyse the results from the final 20 choices by each cow in each experiment. Effectively this means that if a cow chose the correct (food bearing) spur more than 15 times out of the 20 she was deemed to have shown significant signs of understanding the signal ($p<5\%$). In addition, the choices for each cow in each experiment were plotted cumulatively and sequentially over the course of the experiments for visual comparison, i.e. for each trial in order, a correct choice was added to the Y-axis component of the cumulative total, alternatively a wrong choice was added to the X-axis component of the cumulative total.

3 Results

3.1 Experiment 1: Single grey bucket

The data for each cow are presented in figure 3.3a for the experimental cows and figure 3.3b for the control cows. The final twenty choices for each cow are shown in the table 3.5. Cow C980 missed trials 25, 28, 35 and 59. Cow 9592 missed trial 25.

Table 3.5 Experiment 1: Total number of correct or wrong choices in the final twenty trials for each cow with Chi-square coefficient (d.f. = 1)

Cow	Right choices	Wrong choices	Chi-square	Significance
Experimental				
9595	20	0	20	p<1%
C980	13	7	1.8	n.s.
D549	18	2	12.8	p<1%
C506	19	1	16.2	p<1%
Control				
9009	13	7	1.8	n.s.
B825	10	10	0	n.s.

Three of the experimental cows chose the correct spur highly significantly more often than the wrong spur in the final 20 trials.

Figures 3.3a and b show the point at which the food was changed. For the experimental cows this point clearly closely coincided with the point at which the cows started to choose the correct spur.

Cow 980 exhibited aberrant behaviour during the experiment. At the 36th trial she started to choose the wrong spur and continued to do so nine times out of the next 10 trials. For the next seven trials she started to choose the correct spur but did not eat the food. For the remainder of the trial she ate the food and usually chose correctly.

In the first 14 trials (i.e. before the food change) none of the cows, including the controls, chose a particular spur significantly more than the other ($p>5\%$, Chi-square test, d.f. = 1). For the next 14 trials (i.e. after the food change) the control cows both chose one spur significantly more than the other ($p<5\%$, Chi-square test, d.f. = 1). These data are shown in table 3.6.

Figure 3.3a: Cumulative and sequential choices for experimental cows in experiment 1

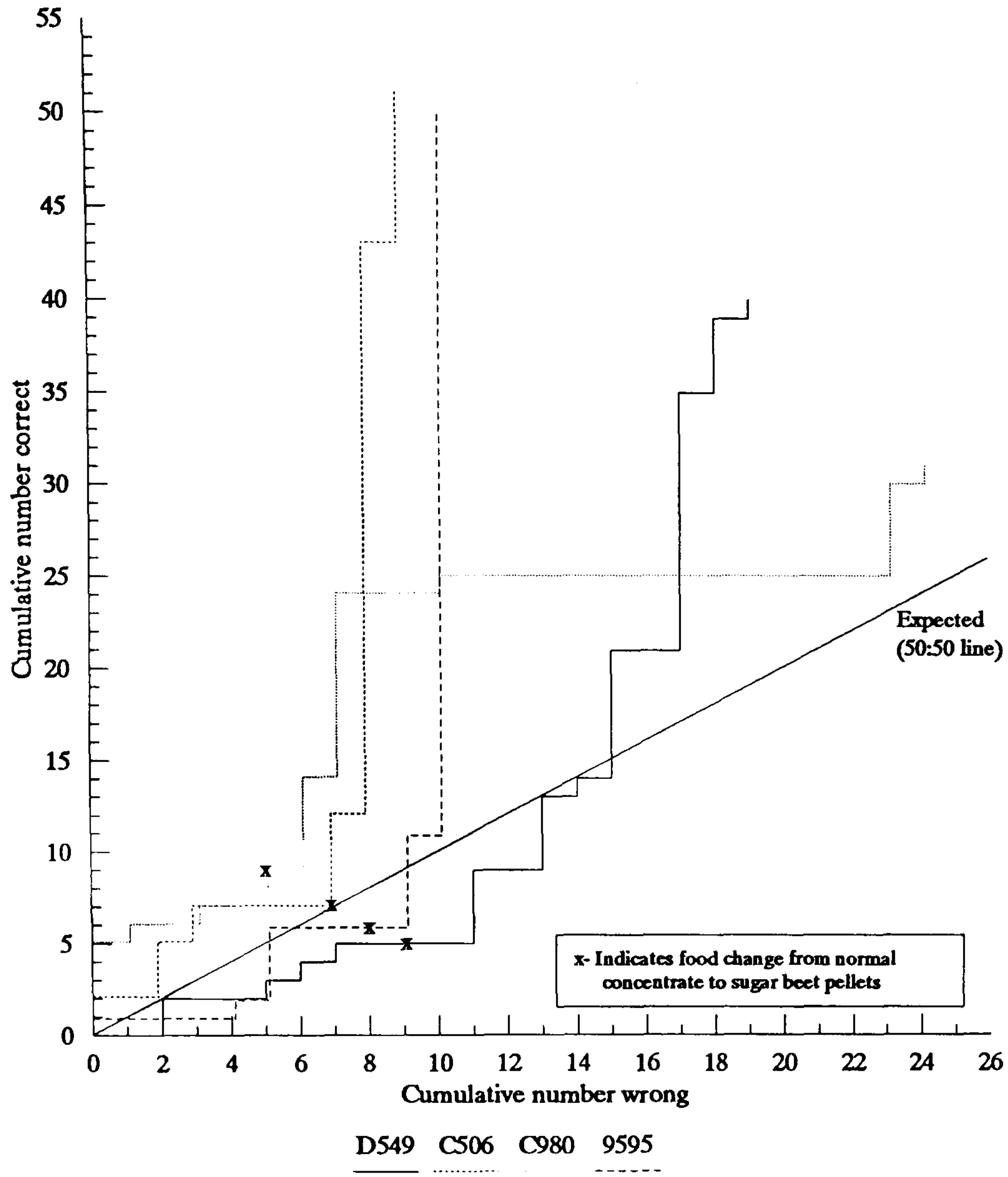


Figure 3.3b: Cumulative and sequential choices for control cows in experiment 1

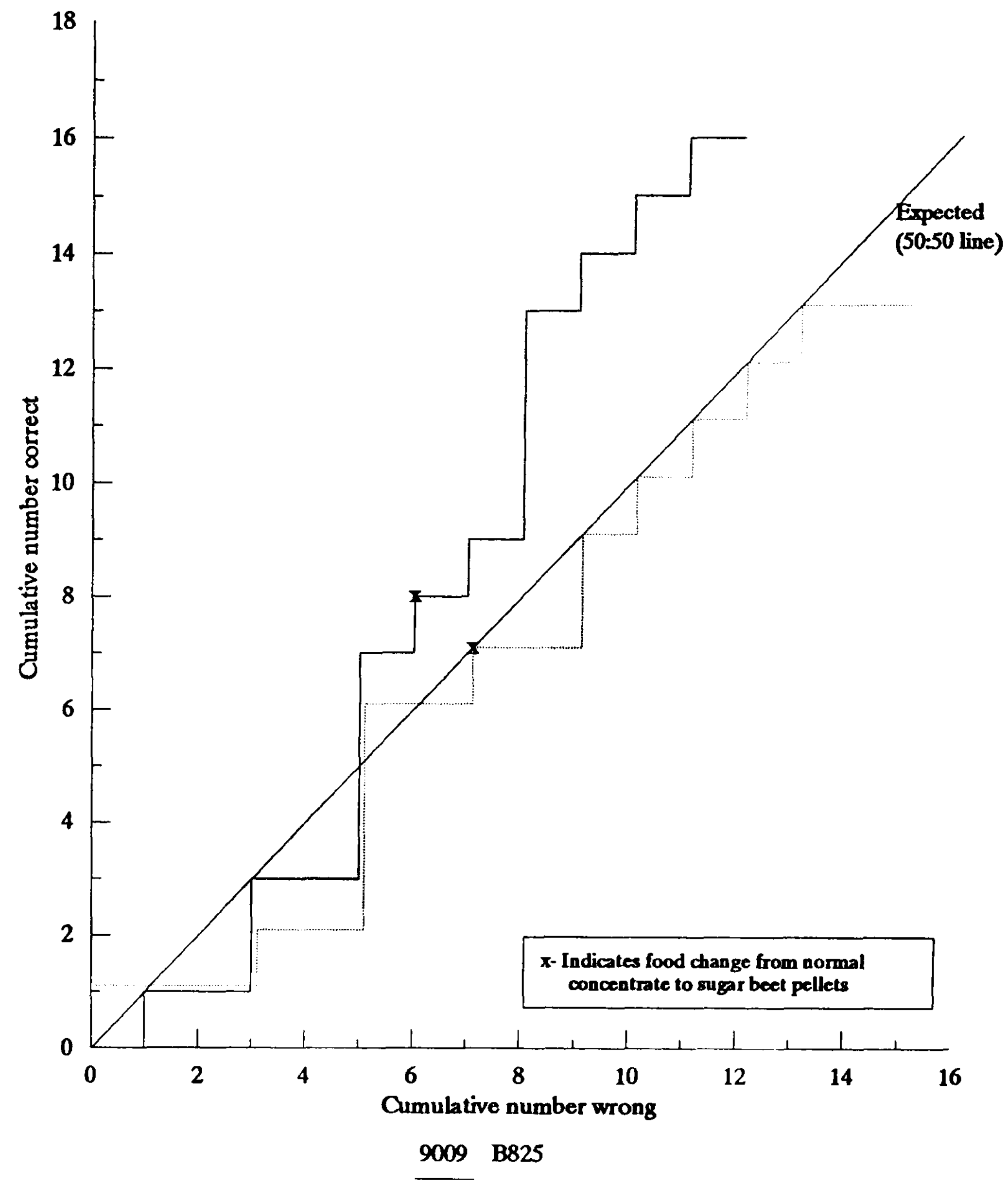


Table 3.6 Total choices by the experimental and control cows for a particular spur in the first and last 14 trials of experiment 1 with Chi-square coefficient (d.f. = 1)

Cows	Right spur	Left spur	Chi-square	Sig.
Experimental: trials 1-14				
9595	8	6	0.1	n.s.
C980	5	9	0.6	n.s.
D549	7	7	0	n.s.
C506	4	10	1.3	n.s.
Control: trials 1-14				
9009	8	6	0.1	n.s.
B825	6	8	0.1	n.s.
Control: trial 17-30				
9009	2	12	3.6	p<5%
B825	12	2	3.6	P<5%

The control cows showed no evidence of following the previous cow through the maze, of their combined 56 trials they followed the previous cow on 32 occasions.

3.2 Experiment 2: Red vs yellow bucket

The cumulative and sequential data for all the cows are shown in figure 3.4a for the experimental cows and 3.4b for the control cows. Cows 9009 and C980 missed the 7th and 8th trial. The number of correct and wrong choices for the last twenty trials for each cow are shown in table 3.7.

Table 3.7 Experiment 2: Total number of correct or wrong choices in the final twenty trials for each cow with Chi-square coefficient (d.f. = 1)

Cow	Wrong choices	Right choices	Chi-square	Significance
Experimental				
9595	5	15	5	p<5%
C980	5	15	5	p<5%
D549	4	16	7.2	p<1%
C506	3	17	9.8	p<1%
Control				
9009	9	11	0.2	n.s.
B825	9	11	0.2	n.s.

All the experimental cows showed some signs of having learned that the colour of the

Figure 3.4a: Cumulative and sequential choices for experimental cows in experiment 2

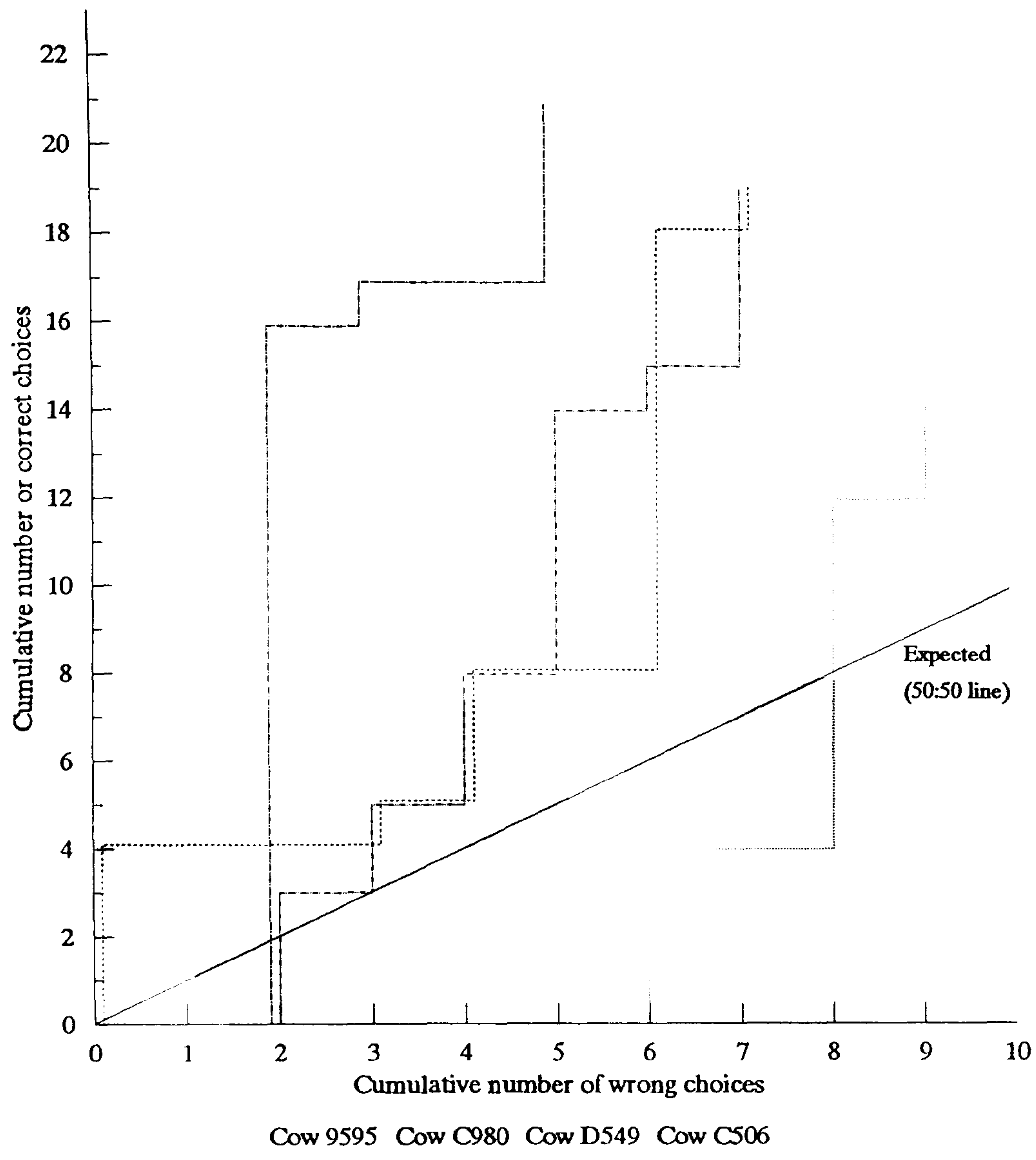
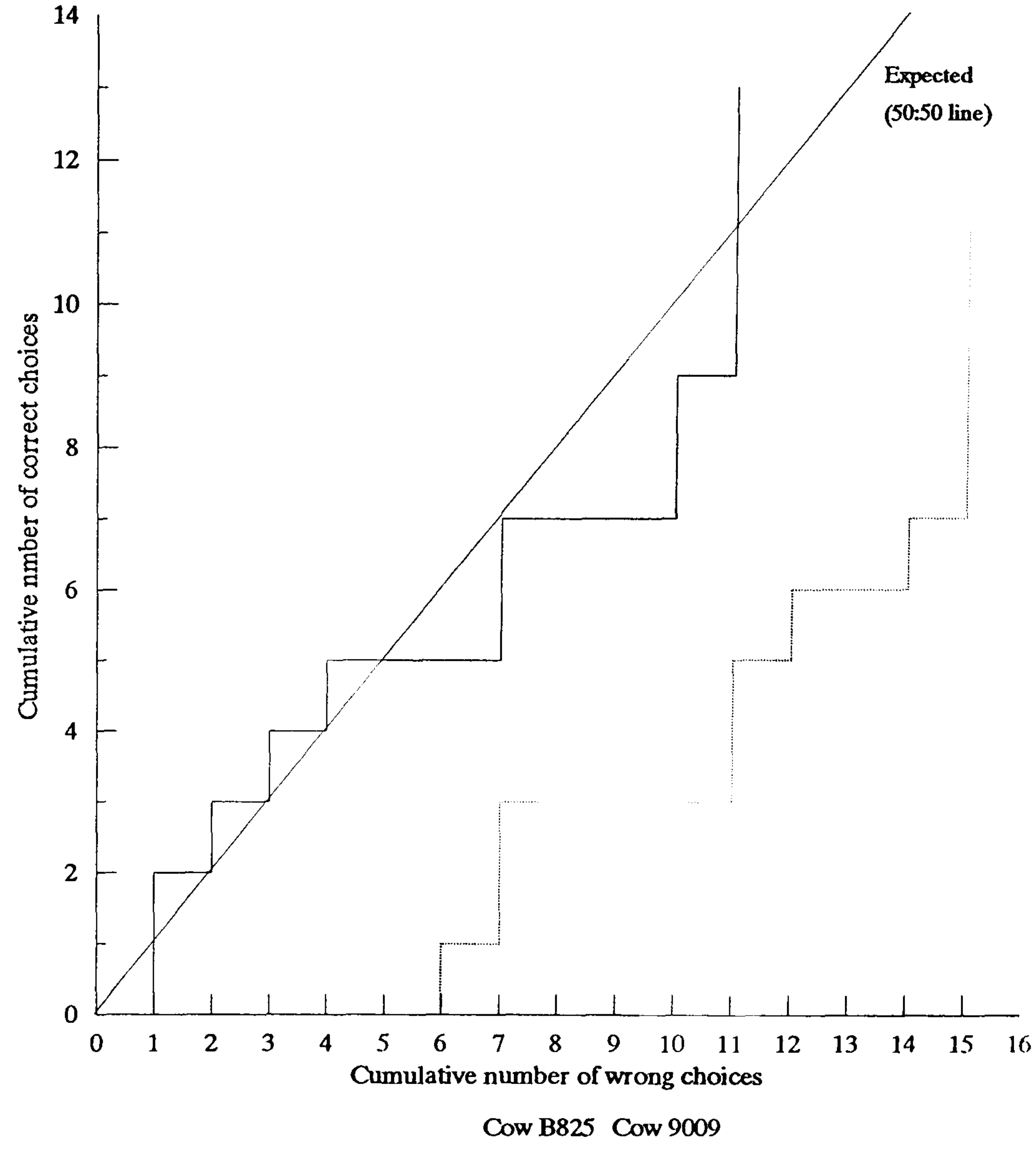


Figure 3.4b: Cumulative and sequential choices for control cows in experiment 2



bucket indicated food, whereas neither of the control cows did.

Cow C980 did not repeat the aberrant behaviour she exhibited in experiment 1.

3.3 Experiment 3: Lit vs dark spur

The data for each cow are plotted in figure 3.5. The results for the final 20 trials are presented in table 3.8. Cow 1176 missed trials 12 and 18. Cow1138 missed the final trial.

Table 3.8 Experiment 3: Total number of correct or wrong choices in the final twenty trials for each cow with Chi-square coefficient (d.f. =1)

Cow	Right choices	Wrong choices	Chi-square	Significance
1004	12	8	0.8	n.s.
1138	12	8	0.8	n.s.
1082	11	9	0.2	n.s.
1176	13	7	1.8	n.s.
1035	13	7	1.8	n.s.
1003	10	10	0	n.s.

No cows exhibited any sign of having learned the signal.

3.4 Experiment 4: Yellow vs. red decision doors

In the first part of this experiment the cows were given the choice between either a red or yellow decision gate, illuminated by the appropriately filtered flashing spotlight. The correct spur contained accessible food and the wrong spur contained an empty bucket. The data for each cow are presented in figure 3.6. The number of right and wrong choices are given in table 3.9 for both the experimental (exp.) period and the control period for the last 20 trials.

Figure 3.5: Cumulative and sequential choices for cows in experiment 3

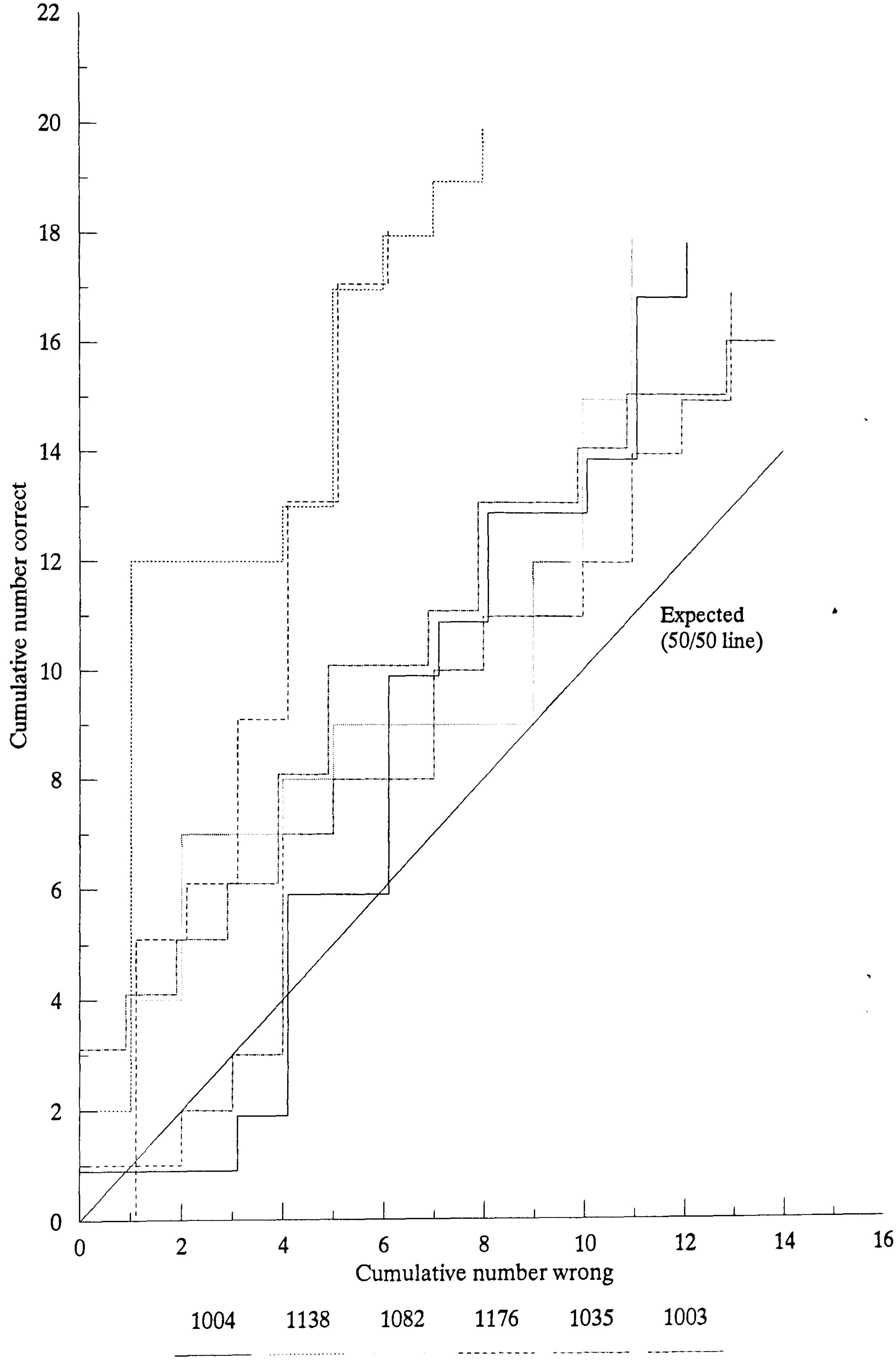


Figure 3.6: Cumulative and sequential choices
for cows in experiment 4 part 1

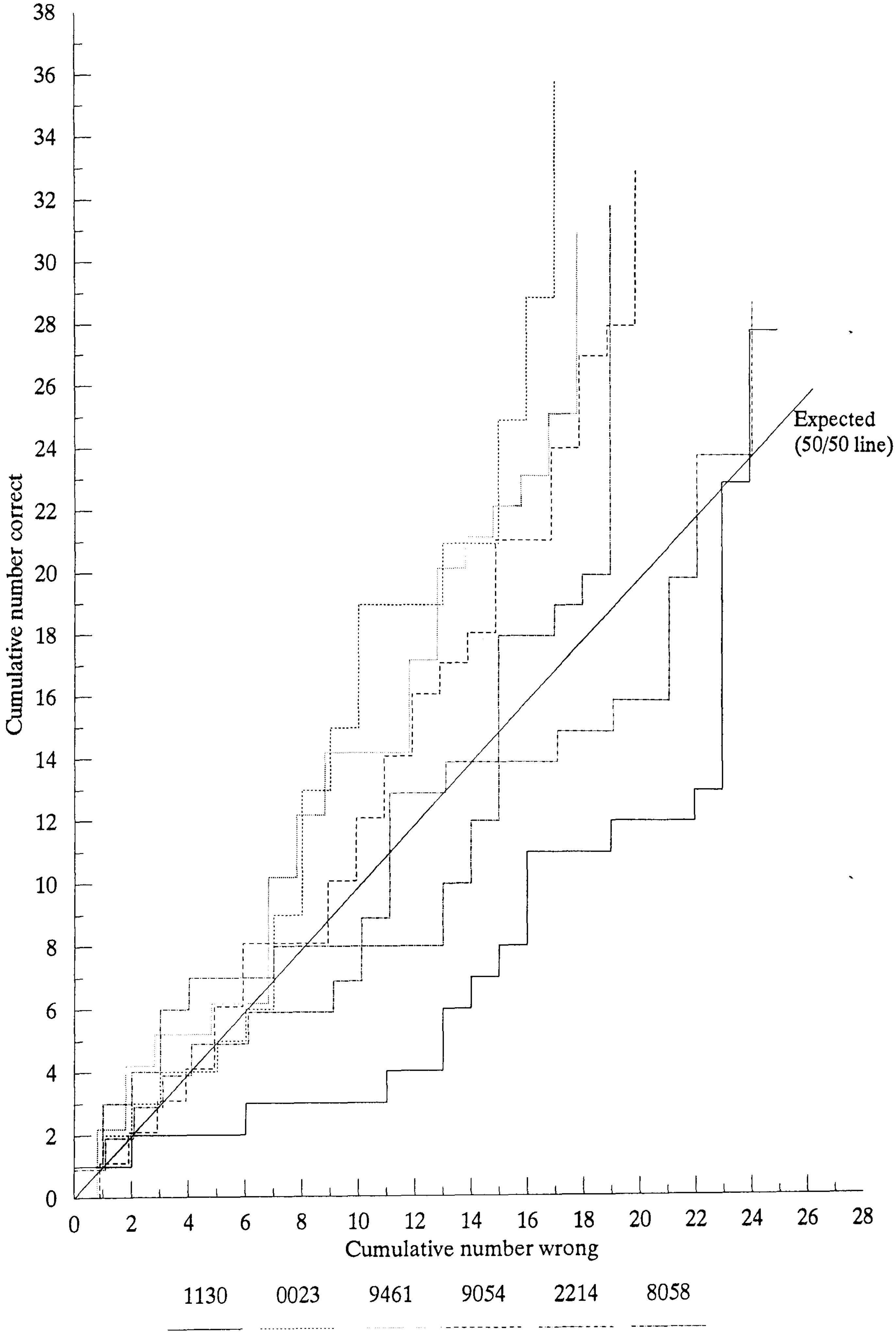


Table 3.9 Experiment 4: Total number of correct or wrong choices in the final twenty trials for each cow with Chi-square coefficient (d.f. =1)

Cow	Right choices	Wrong choices	Chi-square	Significance
Exp. Period				
1130	16	4	7.2	p<1%
0023	16	4	7.2	p<1%
9461	15	5	5	p<5%
9054	15	5	5	p<5%
2214	18	2	12.8	p<1%
8058	17	3	9.8	p<1%
Control Period				
1130	11	0	11	p<1%
0023	9	2	4.5	p<5%
9461	10	1	7.4	p<1%
9054	10	1	7.4	p<1%
2214	11	0	11	p<1%
8058	11	0	11	p<1%.

All the cows chose the correct spur significantly more often than the wrong spur in both the experimental and the control period. The cows must therefore have been choosing the correct spur by using some signal other than the coloured spotlights.

In the second part of this experiment the `wrong' bucket was replaced with the `dummy' bucket, the results for this are shown in the table 3.10 for each cow. Cow 61 missed the final five trials and cow 56 missed trial 19.

Table 3.10 Experiment 4: Total number of correct or wrong choices in the final twenty trials for each cow with Chi-square coefficient (d.f. =1)

Cow	Right choices	Wrong choices	Chi-square	Significance
1130	13	7	1.8	n.s.
0023	11	9	0.2	n.s.
9461	15	5	5	p<5%
9054	13	7	1.8	n.s.
2214	11	9	0.2	n.s.
8058	12	8	0.8	n.s.

Using the `dummy' bucket removed the cows' ability to find the food in the maze for all but one cow (9461).

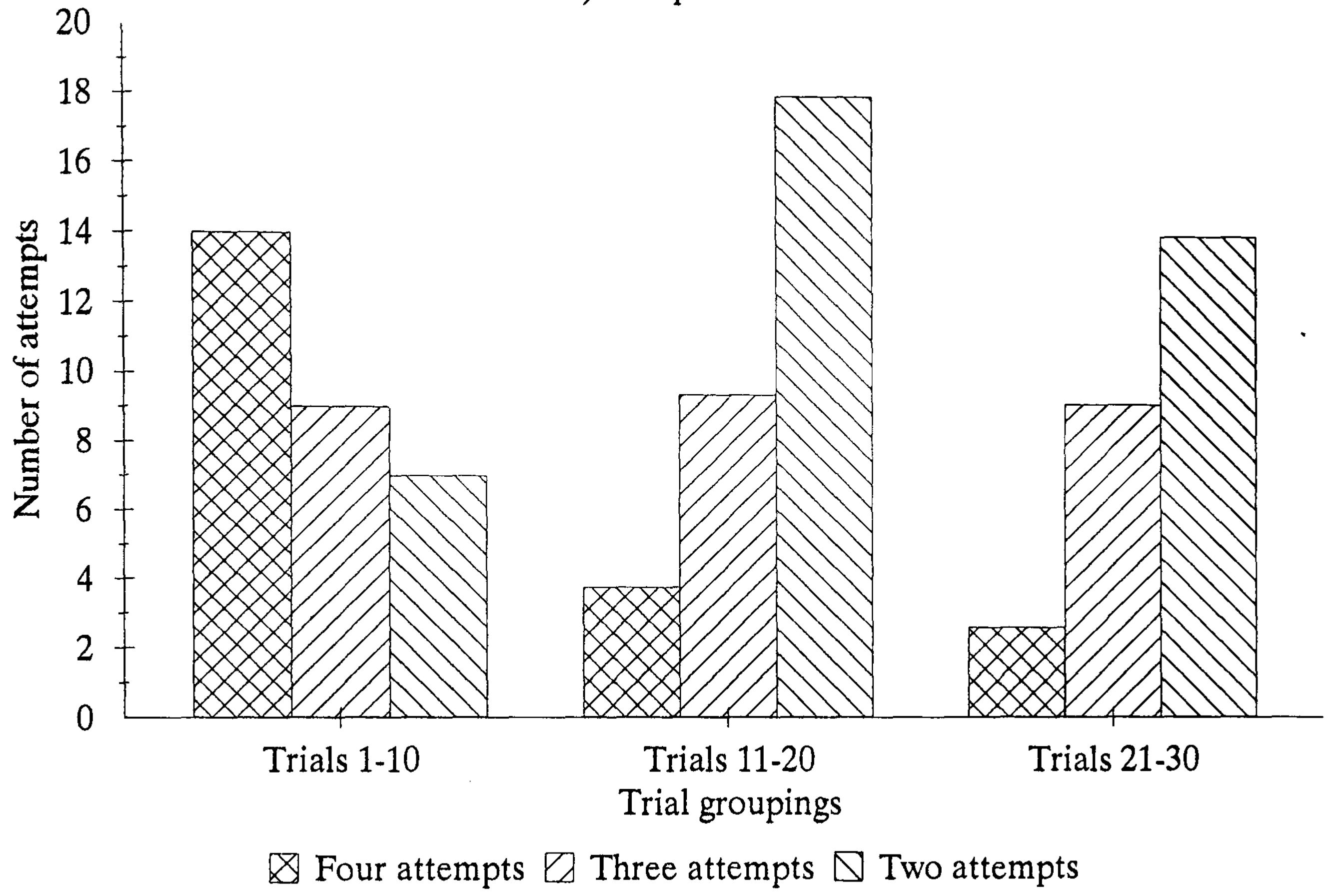
In this experiment when a cow chose the wrong spur, she was allowed another three chances to correct herself before being made to enter the correct spur. Table 3.11 shows the number of tries the cows needed before choosing the correct spur for the first 30 trials. As each 10 trial period had a different number of wrong choices (30, 32 and 23 respectively) the data in brackets indicates the expected frequency for 30 wrong choices. This was derived by scaling the observed data accordingly.

Table 3.11 Number of attempts needed to choose the correct spur for the first three blocks of 10 treatments in experiment 4

Trial number	Four attempts	Three attempts	Two attempts
1-10	14	9	7
11-20	4 (3.75)	10 (9.38)	18 (16.88)
21-30	2 (2.6)	7 (9.13)	14 (18.26)

These data suggest that the number of `goes' needed to choose the correct spur declined during the experiment. These data are plotted in figure 3.7.

Figure 3.7: Number of attempts needed by the cows to choose the correct spur (summed for all cows) in experiment 4



4 Discussion

4.1 Experiment 1 (Single grey bucket)

This experiment showed that the cows could find a food reward in the Y-maze when the food was contained in a single grey bucket, although this took approximately 14 trials. One factor that may have affected the time taken to exhibit learning was the nature of the food reward. When the food was changed from normal concentrate to sugar beet, the cows rapidly began to choose the correct spur, although this may have been coincidence. The result from C980, who appeared knowingly to select the wrong spur and then chose the right spur but not eat the food, may also suggest that the type of food reward is important.

The control cows preferred one or other spur by the 28th trial. This was different for each of the control cows. The reason for this preference is unclear although it may have developed in the training procedure. For the first 15 trials when the cows were not fed at all, they failed to show any preference for either spur, suggesting that the strong motivator (food) at the other end of the maze may have acted to help develop this preference. The control cows showed no signs of following the previous cow through the maze.

4.2 Experiment 2 (Yellow vs. red bucket)

In this experiment, increasing the complexity of the signal did not seem to interfere with the cows' ability to find the food; they soon learned that only one coloured bucket rewarded them. The control cows failed to learn anything suggesting that the nature of the bucket was important. If the cows were finding the correct bucket by another means, such as smell, then the control cows should also have found the food. The control cows did, however, appear to try to find the food since they did not resort to their habit of continually choosing the same spur as they had done in the previous trial. The cows may have been choosing the buckets by their brightness or the small differences in shape since these were not controlled for.

This experiment suggests that the cows could distinguish between the coloured buckets and they could learn this within 20 trials, albeit that they already knew that a bucket indicated food.

4.3 Experiment 3 (Lit vs. dark spur)

This experiment increased the complexity of the signal still further. Instead of the signal being so closely associated with the food it became more abstract. None of the cows showed any signs of having learned to find the food using the signal.

4.4 Experiment 4 (Yellow vs. red decision doors)

A possible problem with experiment 3 may have been that the signal itself could be attractive or aversive. For example, the cows may be reluctant to enter a darkened spur while being attracted to a lit spur. This experiment aimed to remove this interference by using coloured light, both of whose attractive or aversive properties would probably be similar (although this is a presumption). In addition by closing the decision doors, this experiment may have prevented the cows from making any decisions based on what they saw down either spur.

The cows appeared to have learned the nature of the signal but when the signal was removed the cows continued to find the food. They would have been unable to see the bucket being refilled, since both the holding stall doors and the decision doors were closed. It is also unlikely that they would have heard the buckets being refilled. This only leaves the cow's sense of smell as the least unlikely method by which they were so accurately predicting the presence of the food. The second part of this experiment was performed therefore, using the `dummy' bucket, with the presumption that the difference in the smell between the `correct' and `wrong' bucket would have been very small. The buckets themselves were regularly changed. This protocol did appear to remove the ability of five of the cows to find the food, however one cow was still able to find the food. Perhaps she alone had deduced that the intended signal indicated the presence or absence of food.

This experiment also employed a different training procedure whereby the cows were allowed three tries before they were made to use the correct spur. The cows soon learned that if they chose the wrong spur initially, they must choose the alternative spur in the next choice, as indicated by a progressive reduction in the number of wrong choices during the experiment. This suggests that they could remember which spur they had previously used and what the outcome of that was.

4.5 General Discussion

The cows tended to locate the food when the signal was closely related to the reward, i.e. the presence or colour of a bucket. When the signal was made more abstract, the cows showed more variation in their ability to learn. In experiment 4 (red vs. yellow decision doors) the cows appeared to have learned a different signal from that which was intended and significantly chose the food spur without using the intended signal. They may have been tracing the food by the smell, since when the dummy bucket was introduced their ability to find the food was largely removed.

From the first experiment is seems clear that the nature of the reward can be important. It may be that the reward value of an unchanging food reward lessened during the experiment or that the cows have different preferences for the same food. Increasing the value of the reward may increase the speed and uniformity of learning. This could be achieved by determining which foods the cows prefer and randomly presenting them as the reward. The random food changes may also prevent the hypothesised decrease in the reward value of the food with time and ameliorate the problem of individual cows finding one or two foods of low rewarding value

Throughout this chapter (and in chapter 5) I used words like `correct' and `wrong' as well as `learn'. These words are merely convenient ways of explaining the results. They are not meant to suggest that the cows had or had not associated the signals with the food merely that they did or did not show evidence of having acquired the association.

5 Conclusion

The cows appeared to learn readily that a single grey bucket and that one of two differently coloured buckets would provide food rewards. However increasing the complexity of the signal by making it less closely associated with the reward, seemed to remove the cow's ability to learn that the signal indicated a food reward.

The ability of the cows to learn appeared to be related in some way to the nature of the reward. The cows may learn better if a number of foods are randomly presented as the reward.

In the final experiment the cows appeared able to find the food when given no signals as to the location of it. They may have been using their sense of smell.

CHAPTER 4

CONSECUTIVE FOOD CHOICES BY DAIRY COWS

1 Introduction

Chapter 3 showed that some cows did not exhibit consistent signs of learning to find food randomly presented in either spur of a Y-maze, as indicated by an abstract visual signal. One reason for this may have been the nature of the reward. Either the value of the food reward may have been too low for the cows to want to choose it, or the positive reinforcement generated by the food was too weak to allow the cows to associate the position of the food with the visual cues.

The experiment in this chapter was designed to assess food preferences for readily available feeds, allowing a number of preferred foods to be randomly presented as the reward in future signalling experiments. Using a number of foods may ameliorate the effects of weak individual preferences, for a particular food, on the cows' choices in the Y-maze.

Food preferences in cattle have generally been tested operantly (Klopfer et al. 1981, Arave et al. 1983, Matthews and Temple 1979, Moore et al. 1974). Operant tests allow the strength of motivation to ingest a particular food to be assessed but require significant investment of time in training and analysis of the results. Another method, which would have the advantages of requiring little equipment or training, is to give the cows the choice of a number of foods, ranking the food preferences by the order in which the cows eat them. Obviously the strength of the food preferences could not be assessed. The time spent eating would not be a reliable indicator of preference since some foods will take longer to eat than others. For example sugar beet pellets are very hard and chewy in comparison with normal dairy concentrate pellets.

Of the four primary tastes (sour, bitter, salt, sweet) cows ranked sweet over sour followed by bitter and salt (Nombekela et al. 1994). Kudryavtzev however, (quoted in Albright 1993) reported that the taste preferences of cattle changed with time. Cows routinely fed silage had a reduced sensitivity to sour tastes and an increased sensitivity to sweet tastes. Klopfer et al. (1981) ranked the preferences of two cows for 20 feeds in an operant conditioning experiment. The most palatable food was crushed barley, which the cows were willing to work for six times as hard as they would for grass or maize silage. However none of the foods they provided were of intermediate preference between the barley and silage. They also used some foods that were not readily available for example concentrated plant juice, whey and Typha silage. In an operant conditioning experiment Arave et al. (1983) showed that adding a flavouring agent reduced heifers' preference for a particular feed. The heifers also preferred pelleted meal to ground meal suggesting that the physical characteristics of the foods may be important in determining an animal's food preferences.

This experiment determined if dairy cows ate six different foods in a consistent order. Consistent choices where then be used as a measure of preference for each food. This presumed that the cows ate the most preferred foods first.

2 Materials and Method

2.1 Method

This experiment was performed in the exit area of the Y-maze (described in chapter 2). Six cows were allowed to choose between six bowls containing different foods. The bowls were arranged in a line and bolted to a secure base (see figure 4.1 for a diagram). The cows were given this choice three times per day, one in each of three sessions; 09:30-10:30, 11:00-12:00 and 14:00-15:00. Each cow was allowed one seven minute trial per session.

The cows were gathered into the collecting ring, as in previous experiments, and allowed through the maze individually to find the food at the far end. The cow's progress was monitored via a video camera positioned above the apparatus and connected to a remote video recorder and monitor. When each cow's trial was finished, she was returned to the living area via the return race. The bowls were then washed, refilled and the next cow allowed in.

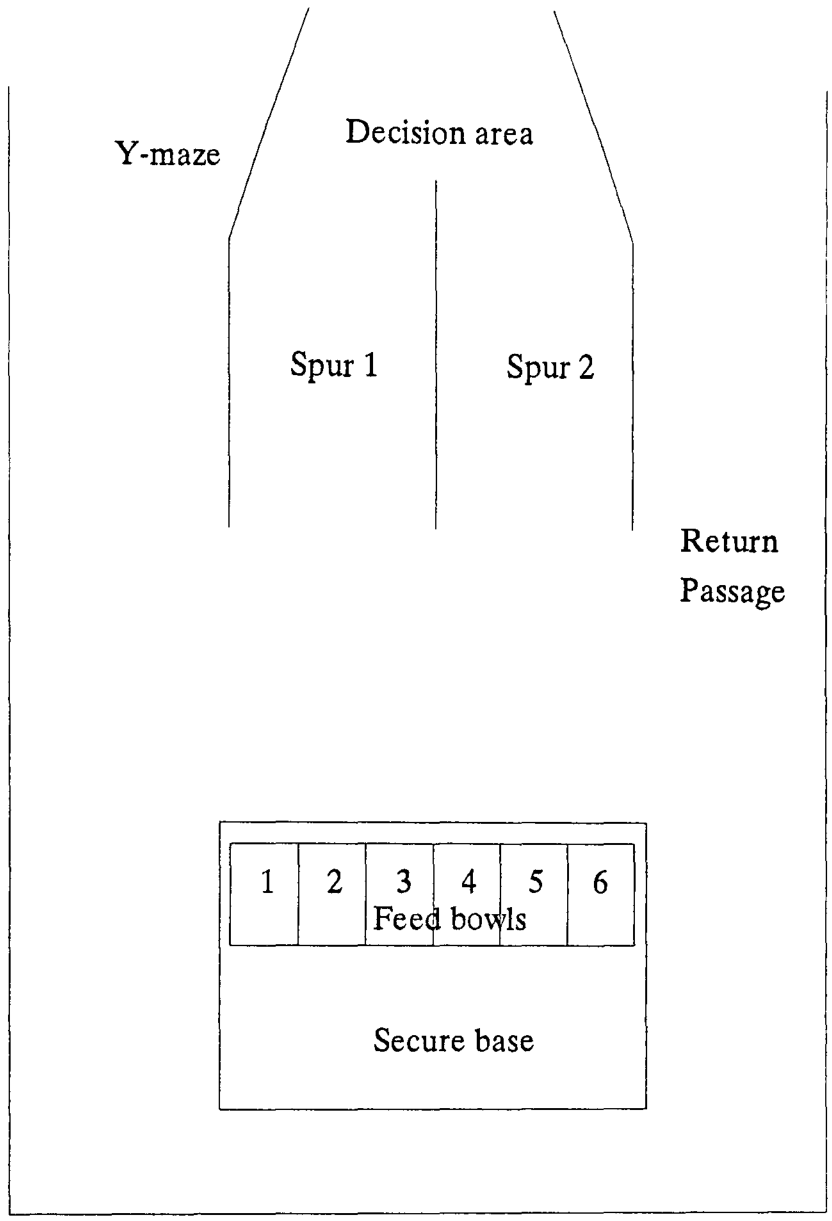
To ensure that the cows were not simply choosing a particular food because of the position it was in, the position of each food was changed between bowls for each trial according to a schedule. There were five schedules, one of which was used for each trial. These schedules are shown in table 4.1.

Table 4.1 Position of each food for the five schedules in one of the six bowls (numbered 1-6)

Schedule Number	1	2	3	4	5
Silage	4	3	2	5	1
Coarse Ration	5	4	3	6	2
Vegetable Mix	6	5	4	1	3
Sugar Beet	1	6	5	2	4
Pasture Nuts	2	1	6	3	5
Normal Concentrate	3	2	1	4	6

When not being tested, the cows were kept with the main herd. They were milked in the farm's main parlour before the first morning trial and after the last afternoon trial. During the experimental day they had access to cubicles, a small courtyard, water and hay.

Figure 4.1: Position and form of food choice apparatus relative to the Y-maze



2.2 Foods

A brief description of each food is given in table 4.2. A fuller description is given in appendix 4. The foods were chosen based on convenient and constant availability.

Table 4.2 Foods used

Normal Concentrate **(NC)**- BOCM/Pauls 1592 Dairy Nuts
Pasture Nuts **(PN)** - Dodson and Horrell (Horse feed)
Sugar Beet Pellets **(SB)**- Trident feeds
Wet Sugar Beet **(WSB)**- Sugar beet pellets soaked overnight
Soaked/Sugared Sugar Beet **(WSSB)**- Above + 1kg sugar/5kg sugar beet
Vegetable Mix **(VM)**- Chopped cabbage, potato, tomato, apple, swede.
Lettuce **(L)** - Fresh shredded lettuce
Sugared Water **(SW)**- 1kg sugar/ 5l water
Coarse Ration **(CR)**- Dalgety coarse 16 mix
Silage **(S)**- Maize and grass silage mix

Only six of these foods were presented at any one time. The choice of foods offered in any one day are shown in the table below, where the abbreviations are explained in the table above.

Table 4.3 Food provided each day

Day	1	2	3	4	5	6	7	8
	S	S	S	S	S	S	SB	SB
	CR	CR	CR	CR	CR	CR	CR	CR
	VM	VM	VM	SW	WSB	WSB	L	L
	SB	SB	SB	SB	SB	SB	WSSB	WSSB
	PN	PN	PN	PN	PN	PN	PN	PN
	NC	NC	NC	NC	NC	NC	NC	NC

The results for the first five and last two days were analysed separately. The results for day six were not used in the analysis because three of the cows were undergoing pregnancy diagnosis.

2.3 Data recording

The order in which each cow ate the various foods was recorded. If a cow sampled a bowl for less than five seconds, it was not recorded. Whether or not a cow had finished the food in each bowl was also recorded. The foods were ranked in the order in which each cow ate them. If a cow did not eat from one or some of the bowls then these were ranked as last equal. Return visits to a bowl previously eaten from were not analysed.

2.4 The cows

The cows were selected from the main herd at Cheseridge Farm, belonging to the Institute for Animal Health, Compton. The selection criteria were young, quiet cows with good hooves and in late lactation. They are described in the table below, where DIM refers to days in milk.

Table 4.4 Cow details

Cow	Parity	DIM (days)	Yield (l)
974	1	176	11.0
9590	3	169	12.2
997	2	157	13.7
505	1	172	12.3
0028	1	181	12.7
276	3	186	13.2

3 Results

3.1 Part 1: Results for the first five days

Table 4.5 shows the summed preference ranks from each of the six cows for each trial for the first 5 days. The `Misc.' column shows the summed ranks for the foods bracketed within it.

Table 4.5 Summed ranks for all of the six cows for each food for each trial

Day	Sch.	Trial	NC	PN	CR	SB	S	Misc.
1	2	1	8	17.5	20	21.5	31.5	26.5 (VM)
	3	2	9	18	21	17	33.5	28 (VM)
	4	3	13	15	18.5	20	33	26.5 (VM)
2	5	1	8	18	19.5	22	28	30.5 (VM)
	1	2	9	16.5	18	22.5	31.5	28.5 (VM)
	2	3	11	19.5	13.5	25	30	27 (VM)
3	4	1	8	15	17	27.5	30	28 (SW)
	5	2	12	13	17	26.5	30.5	26 (SW)
	1	3	9	16	14	28.5	27.5	30.5 (SW)
4	3	1	7	15	14	29	31.5	29.5 (WSB)
	4	2	9	17	11	27.5	32	29.5 (WSB)
	5	3	11	17	10	26.5	28	33.5 (WSB)
5	1	1	8.9	13.2	14.4	30	30.6	16.2 (WSSB)
	2	2	6	14.4	15.6	31.8	28.8	29.4 (WSSB)
	3	3	12	18	6	32.4	30.6	27 (WSSB)

These data are graphically represented in figure 4.2. The ranks throughout the five days were consistent, the NC, PN and CR were preferred to the S, SW, SB, WSB and VM. There was a significant change with time in the summed rank of the CR (progressively chosen earlier, p<1% Spearmen's rank, n=15) and the SB (progressively chosen later, p<1% Spearman's rank, n=15). This can be seen in table 4.6, where the significance of the trends (derived from the Spearman's rank test) for each food type is shown, along with the Spearman's rank correlation coefficient.

Figure 4.2: Summed ranks for all cows for each food type

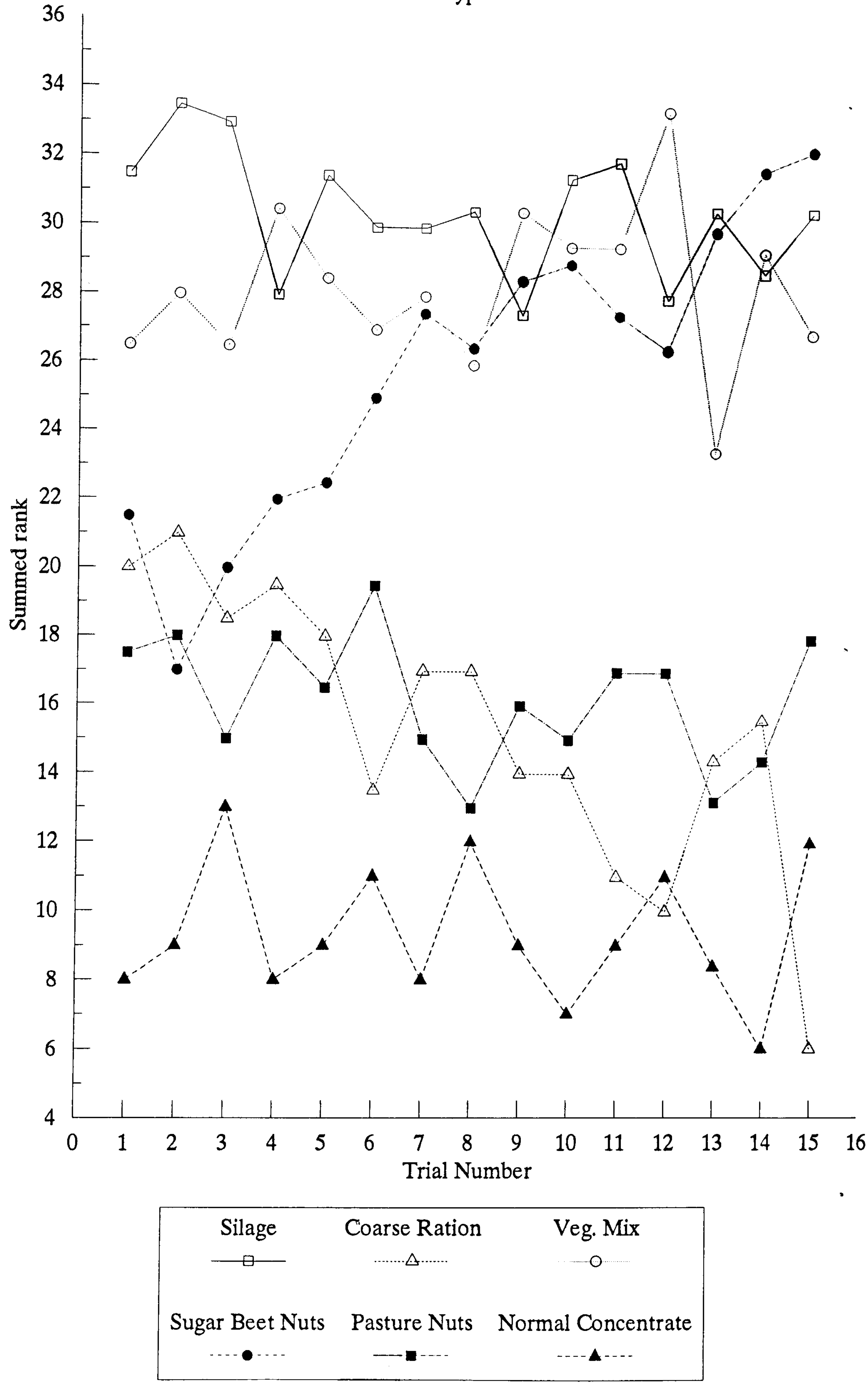


Table 4.6 Correlation analysis data illustrating changes in food preference over time (level of significance derived from the Spearman's rank test, n=15)

	Spearman rank correlation coefficient	Significance
Silage	-0.28	n.s.
Coarse Ration	-0.81	P<1%
Vegetable Mix	0.19	n.s.
Sugar Beet	0.89	P<1%
Pasture Nuts	-0.31	n.s.
Normal Concentrate	0.04	n.s.

Figure 4.3 show the best-fit curves for CR and SB over the first five days.

While the group effect is clear, the individual preference changes for SB and CR are not. Table 4.7 shows the level of significance for changes in preference with time for each cow.

Table 4.7 Individual cow correlation data for changing preferences for CR and SB using the Spearman's rank test (n=15)

Cow no.	974	9590	997	505	0028	276
SB	P<10%	**P<1%**	n.s.	**P<1%**	n.s.	**P<1%**
CR	n.s.	**P<5%**	n.s.	P<10%	P<10%	n.s.

Therefore the changes seen in table 4.6 were largely a result of three cows (9590, 505 and 276) showing highly significant trends, the remaining three cows (974, 997 and 0028) failed to show any significant change in their preference.

The frequencies with which each different food were finished are shown in table 4.8.

Table 4.8 Frequency of times that each food was finished in part 1

Food	NC	PN	CR	VM	S	SB
Frequency	94%	70%	60%	6%	3%	2%

NC, PN and CR were often finished, while VM, S and SB were rarely finished.

3.2 Part 2 Results for the last two days

The final two days of the experiment assessed the preference of the cows for WSSB, L. CR, PN, NC and SB. The rank preference results for the WSSB and L are shown in table 4.9.

Table 4.9 Summed ranks from each of the six cows for WSSB and L in part 2

Day	Schedule	Trial	L	WSSB	SB
1	1	1	25.5	21.5	25.5
	2	2	25	17.5	26.5
	3	3	25	17.5	22
2	4	1	26.5	15	26.5
	5	2	27.5	10	27.5
	1	3	26	17.5	27.5

These data are represented in figure 4.4. The cows showed little preference for the lettuce or the sugar beet. There was a trend for the cows to prefer the WSSB increasingly. Ignoring the last trial's result, this trend was significant (p<5%, Spearman's rank, n=5).

The WSSB was significantly (P<5%, Wilcoxon matched pairs test, n=6) more attractive compared with the ordinary, dry sugar beet pellets.

The frequency with which each food was finished in part 2 is shown in table 4.10.

Table 4.10 Percentage of times that each food was finished in part 2

Food	NC	CR	PN	WSSB	SB	L
Frequency	88%	79%	59%	32%	0%	0%

Again the NC, CR and PN were often finished, the WSSB was also often finished. L and SB were never finished.

3.3 Preferences for particular bowls

This analysis was designed as a control to determine if the cows had any preference for a particular bowl, irrespective of the food it contained. The same system of ranking was used as in the analysis above. The rank preferences of each cow, for each of the six bowls, for each trial, were summed and a Chi-square analysis was used to compare the expected versus the observed total rank. No cow showed any significant preference for any bowl (p>5%, Chi-square, n=20).

Figure 4.3: Regression curves showing change in summed rank with time, shown for CR and SB

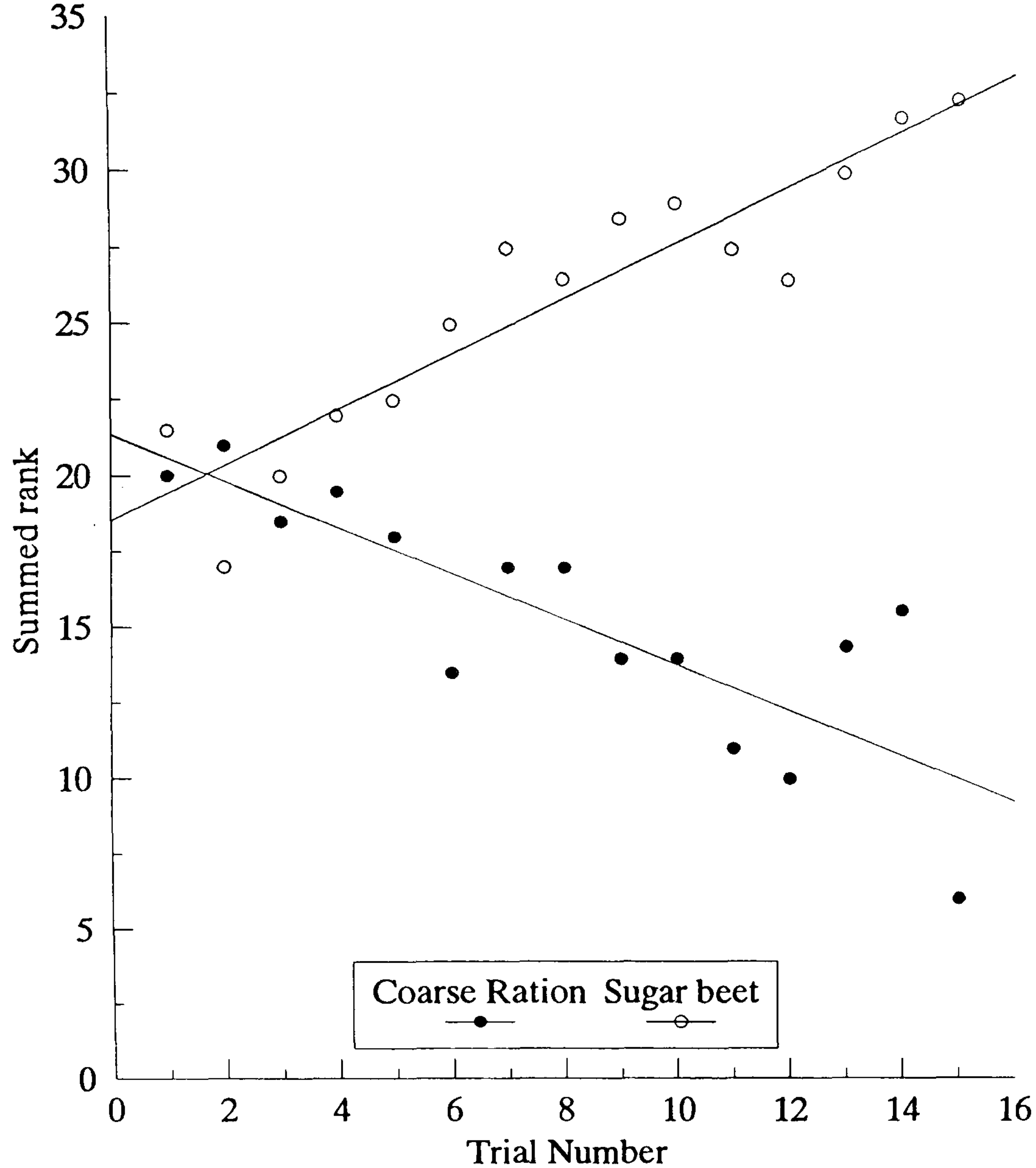
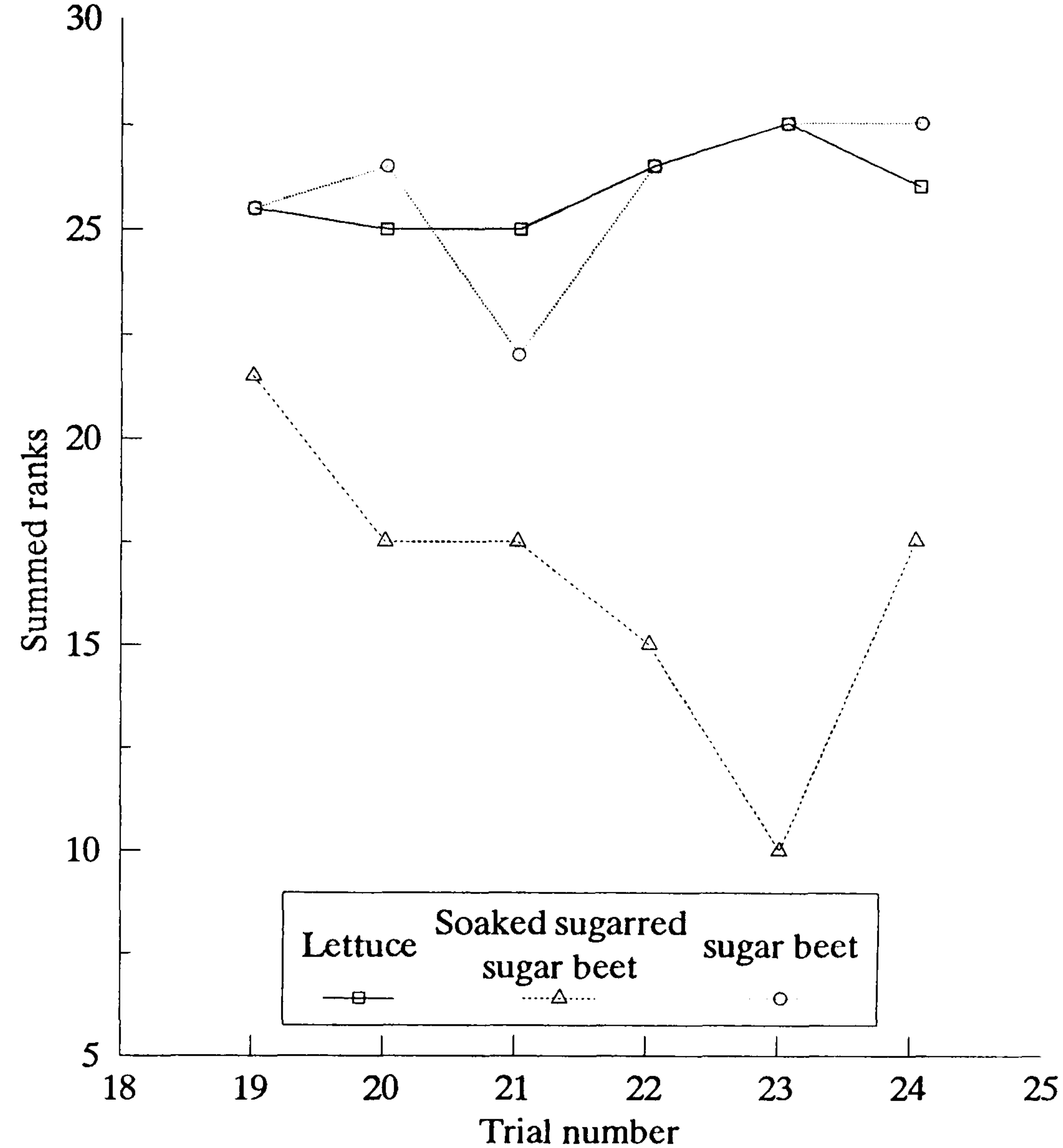


Figure 4.4: Change in summed rank (with best fit curves for lettuce, sugar beet, and soaked sugarred sugar beet



4 Discussion

The cows actively and consistently choose between the different foods. These preferences also had a degree of dynamism with some cows changing their preferences for CR and SB. The SB and the CR showed opposite trends during the experiment, the CR became more preferred and the SB became less preferred. The increasing preference for CR suggests an acquired taste that overcame any initial neo-phobia. The increasing dislike of the SB may be because it is hard, chewy and not particularly sweet; indeed, even at the start of the experiment, this food was rarely finished. The NC, which the cows are fed every day, was the most preferred food throughout the experiment. Either this food was very palatable or the cows preferred it out of habit. The regular, and rationed, use of concentrate in dairy cow diets may have disproportionally increased its positive reinforcing value. The silage and vegetable mix were of universal low preference, in fact they were sampled occasionally and rarely finished. The cows generally preferred to lick one or other of the empty feed bowls. These foods may have been weaker tasting or less sweet than the other foods. The acidity of silage may also have affected its palatability.

The variation in the response of the cows to the SB and CR may indicate that food neo-phobia varies between cows. During the first half of the experiment it can be concluded that by the fifth day the cows were showing a strong preference for the NC, PN and CR both in the order in which they ate the foods and the frequency with which they finished each food.

In the second part of the experiment the cows showed similar trends except for an increasing preference for the WSSB. The cows rarely sampled the lettuce.

The cows seemed to dislike the sugar beet in its normal pelleted form. When the pellets were soaked, their preference for it remained low. When the pellets were soaked and sweetened, however, the cows started to show an increasingly strong preference for it. This suggests that, here, while the form of the feed may have been important, taste was more important.

In future preference test experiments, where food is one treatment, it will be possible to give the cows one of four randomly presented preferred foods (NC, PN, CR and WSSB) at each trial. This will ensure that all the cows will usually be rewarded by access to a food which they find positively reinforcing.

5 Conclusion

The cows made consistent choices based on their ranked preferences for certain foods within a short period. This experiment may be useful in other preference work, where food is one treatment, because four feeds (NC, PN, CR, WSSB) have been identified which the cows appear to find palatable. One of these can be randomly presented at each trial to ensure that each cow will find the food reward strongly positively reinforcing.

The cows appeared to have little interest in the forage type feeds when given the choice between these and concentrate type feeds.

Appendix 4

Table 4a Details of foods used during the experiment

Food	Manufactures Address	Ingredients
Normal Concentrate (Dairy 1592 nuts)	BOCM/Pauls Ltd. P.O. Box 49 47 Key Street Ipswich IP4 1BX	Wheatfeed, citrus, rapeseed, palm kernal, sunflower, soyabean hulls, molasses, oil blend, minerals and vitamins Fibre 12% Ash 9% Protein 16% Oil 3%
Pasture nuts	Dodson and Horrell Ltd. Ringstead, Kettering, Northhampton, NN14 4BX	Oat feed, chopped cereal straw, wheatfeed, molasses, linseed, ground limestone flour, salt minerals and vitamins Fibre 23% Ash 9% Protein 8% Oil 2.5%
Sugar beet pellets	Trident Feeds Ltd. P.O. Box 11, Peterborough PE2 9QX	Total sucrose 21% Fibre 12%
Coarse ration (166 Superstock Coarse 16 Mix)	Dalgety Agriculture Ltd. 180 Aztec Way, Almondsbury, Bristol BS18 4TH	Cereals, oil seed products and by-products, Sugar production products and by-products, dried forages, legume seed products and by-products, high fibre materials, minerals, cereal grain products and by-products, oils and fats. Protein 16% Ash 9.5% Fibre 8.5% Oil 3.25%
Wet sugar beet	-	Sugar beet pellets soaked overnight
Soaked/ sugared sugar beet	-	Sugar beet pellets soaked overnight then 1kg of sugar added to every 5kg of sugar beet pulp
Vegetable mix	-	Cabbage, potato, tomato, apple and swede in equal quantities
Lettuce	-	Shredded `Pound' lettuce
Sugared water	-	1kg of sugar dissolved in 5l of water
Silage	-	See chapter 2, section 1

CHAPTER 5

THE RESPONSE OF DAIRY COWS TO VISUAL SIGNALS INDICATING THE LOCATION OF FOUR RANDOMLY PRESENTED FOOD REWARDS IN A Y-MAZE

1 Introduction

There were a number of questions from chapter 3 regarding the ability of cows to associate visual signals with food randomly presented in either spur of a Y-maze.

1) Would cows show signs of learning that different coloured buckets contain different types of food? In experiment 2 of chapter 3 it was shown that cows quickly learned that a particular colour of bucket gave them a food reward. Experiment 1 in this chapter was designed to test whether the cows still show a response when each colour of bucket contained different types of food.

2) Can the level and consistency of the learned response be improved by the reward of four randomly presented foods? The poor results shown by some cows in some of the chapter 3 experiments may have been due to the cows not being motivated enough to associate, or show evidence of associating, the signals with the food. Chapter 4 found four foods which the cows apparently preferred to other foods. Experiment 2 in this chapter used these four foods, presented randomly as the reward, with a strong but abstract visual signal (that of a lit or dark spur), to determine if there is any improvement in the signs of learning.

3) In experiment 4 in chapter 3 it was shown that the cows appeared to have learned to find the randomly presented food in the maze but this ability was unaffected by the absence of indicative signals. Using the `dummy' bucket (see chapter 3) appeared to reduce the ability of the cows to find the food. In Experiment 3 in this chapter the cows were not given any signals as to the location of the food in the Y-maze. This was to determine if the cows could find the food by another method. It was also to identify if the significant results shown in earlier experiments were justified in suggesting that some cows had understood the signals. Some of the significant results may have been due, in some part, to the pattern of swopping the food reward between the two spurs. In this experiment the four foods were randomly presented as the reward (thereby maximising motivation and giving the best chance for the cows to show some significant evidence of learning).

This chapter is similar to chapter 3 in that the experiments reported were a selection of a larger series of pilot trials. Again words like `correct' and `wrong' were used but this was not meant to imply that the cows had or had not learned the nature of the signals, it was simply a convenient way of presenting the results.

2 Materials and Methods

2.1 Materials

The maze has been described in chapter 2.

2.2 General method

The general method has been described in chapter 3.

2.3 The cows

Three groups of six cows were selected from the dairy herd at Cheseridge Farm, belonging to the Institute for Animal Heath, Compton. The cows were selected on the following criteria; healthy, good hooves, late lactation and of quiet disposition. The cows in group 1 were the same as those in group 1 in chapter 3. The cows in group 2 were the same as those used in chapter 4. The cows in group 3 had no experience of the maze. Details of the group 3 cows are given in table 5.1, details of the group 1 and 2 cows can be found in chapters 3 and 4.

Table 5.1 Details of the group 3 cows

Cow	Parity	DIM (days)	Yield (l)
1033	1	234	15.7
1146	1	267	14.3
519	3	258	12.7
527	3	242	14.7
359	5	263	13.9
53	1	247	15.1

2.4 Training

The training method has been described in chapter 3.

2.5 The treatments.

2.5.1 Experiment 1

This experiment was divided into two parts. The first used sugar beet pellets (SB) and normal concentrate (NC) in appropriately coloured buckets. The cows had 28 trials each. The second part consisted of the cows being given the choice of pasture nuts

(PN) or NC, again in appropriately coloured buckets, for 36 trials. Each food was always placed in a particular coloured bucket, and the buckets randomly swopped between the two spurs. The red bucket was placed in the spur shown in the sequence detailed in the general method of chapter 3. There were four experimental cows (9595, C980, D549 and C908) and two control cows (9009 and B825). The experimental cows were divided into two groups. For each group the colour of the bucket that contained each food was the reverse of that for the other group. The experimental design is described in table 5.2.

Table 5.2 Coloured bucket designation for each cow in experiment 1

Cow	SB (part 1) or PN (Part 2)	NC
9595	Red bucket	Yellow bucket
C980	Red bucket	Yellow bucket
D549	Yellow bucket	Red bucket
C908	Yellow bucket	Red bucket
9009	Either bucket	Either bucket
B825	Either bucket	Either bucket

The cows were trained to associate both coloured buckets with the appropriate food by feeding them one food four times in succession in either spur, followed by the other food; this process was repeated four times. When the SB was replaced by PN the training procedure was repeated.

2.5.2 Experiment 2

This experiment was similar to experiment 3 of chapter 3 in detail, except the cows were randomly presented with one of four foods. The random order of presentation was;

NC PN CR PN WSSB CR NC WSSB PN NC WSSB CR PN NC WSSB PN

(Where NC= Normal concentrate, PN= Pasture nuts, CR= Coarse ration and WSSB= Wet soaked, sugared sugar beet pellets. For details of these foods see Appendix 4).

In this sequence each food was presented an equal number of times and no food was presented twice or more in a row, to reduce the potential for a cow to lose motivation if she did not like a particular food.

The location of the food was denoted by the food spur being lit or dark (see experiment 3 chapter 3). Three cows were fed in the dark spur and three in the lit spur. The treatment for each cow is shown in table 5.3.

Table 5.3 Treatments in each spur in experiment 2

	Fed	Not Fed
276	Lit spur	Dark spur
0028	Lit spur	Dark spur
505	Lit spur	Dark spur
974	Dark spur	Lit spur
9590	Dark spur	Lit spur
997	Dark spur	Lit spur

The random position of the lit spur is given in the general method in chapter 3. The `not fed' spur contained the dummy bucket. The cows were each given 53 trials.

In this experiment the cows were free to make up to three wrong choices before being guided down the correct spur, as described in the general method in chapter 3.

2.5.3 Experiment 3

This experiment involved randomly swopping the food, in a large grey plastic bucket, between the two spurs, with the `dummy' bucket in the alternate spur. The cows were divided into two groups of three and each group was fed in the opposite spur to the other group in any one trial. The sequence of random feeding of the different foods was the same as shown in the general method of chapter 3. The cows were each given 50 trials.

2.6 Statistical Analysis

The statistical analysis was similar to that described in chapter 3.

3 Results

3.1 Experiment 1 (Red vs. yellow bucket containing different foods)

The data are presented cumulatively and sequentially in figure 5.1a. Cow 9009 missed the first six trials. The number of NC and SB choices for the last twenty trials of this part are shown in table 5.4.

Table 5.4 Food type choices (NC vs. SB) for the last twenty trials for each cow in experiment 1 (part 1). With Chi-square coefficient (d.f. =1)

Trials Category	NC choices	SB choices	Chi-square	Significance
Experimental Cows				
9595	10	10	0	n.s.
C980	14	6	3.2	n.s.
D549	12	8	0.8	n.s.
C908	8	12	0.8	n.s.
Control Cows				
9009	10	8	0.2	n.s.
B825	10	10	0	n.s.

No cows showed any significant preference for either the NC or the SB.

The data for part 2 are presented cumulatively and sequentially in figure 5.1b. The number of NC and PN choices for the last twenty trials for each cow are shown in table 5.5.

Table 5.5 Food type choices (NC vs. PN) by for the last twenty trials in experiment 1 (part 2). With Chi-square coefficient (d.f. =1)

Cow	NC choices	PN choices	Chi-square	Significance
Experimental cows				
9595	8	12	0.8	n.s.
C980	11	9	0.2	n.s.
D549	7	13	1.8	n.s.
C506	8	12	0.8	n.s.
Control cows				
9009	10	10	0	n.s.
B825	11	9	0.2	n.s.

In the second part of the experiment none of the cows exhibited any significant preference for the NC or the PN.

Figure 5.1a: Cumulative and sequential choices
for cows in experiment 1 part 1

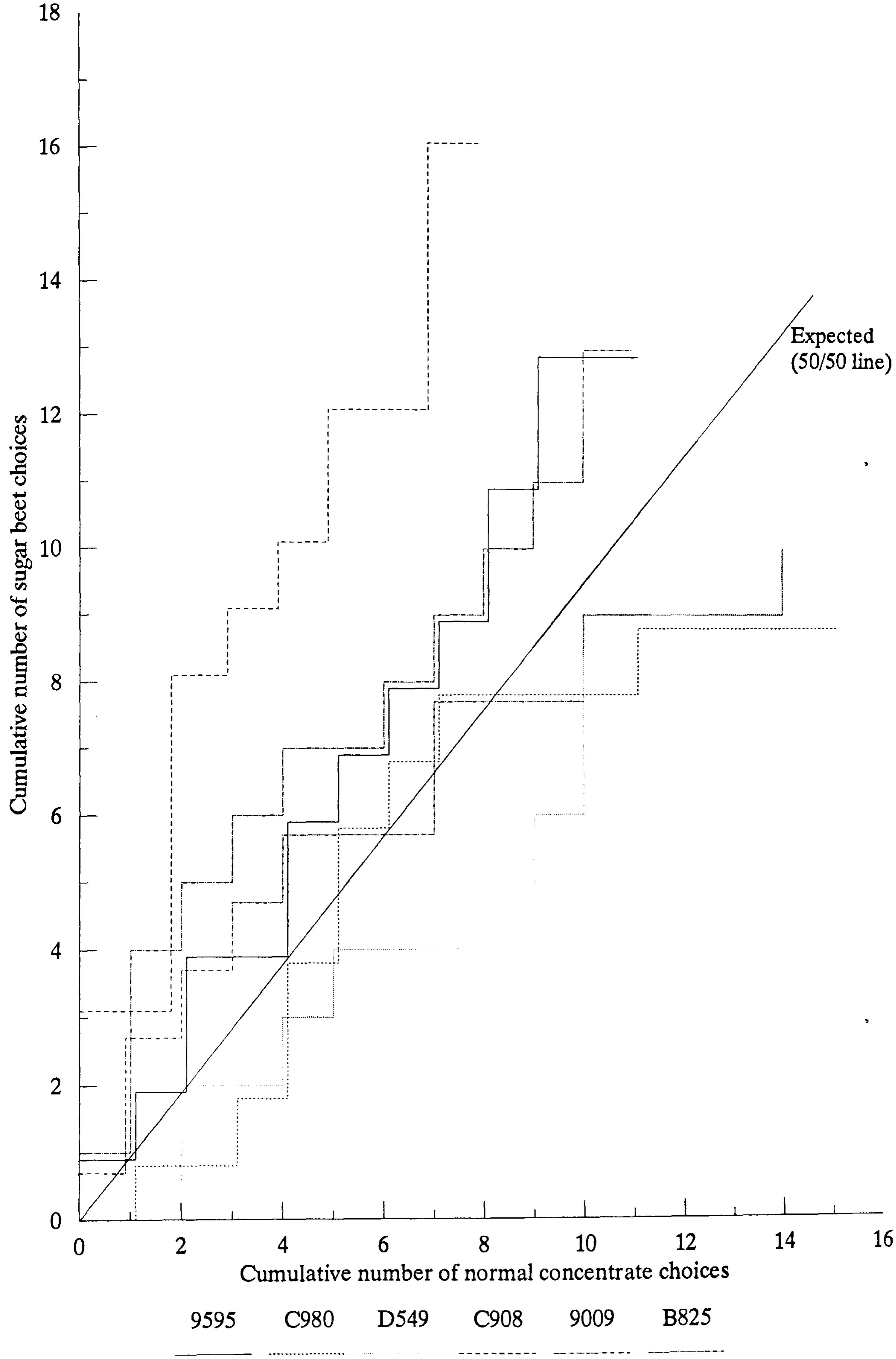
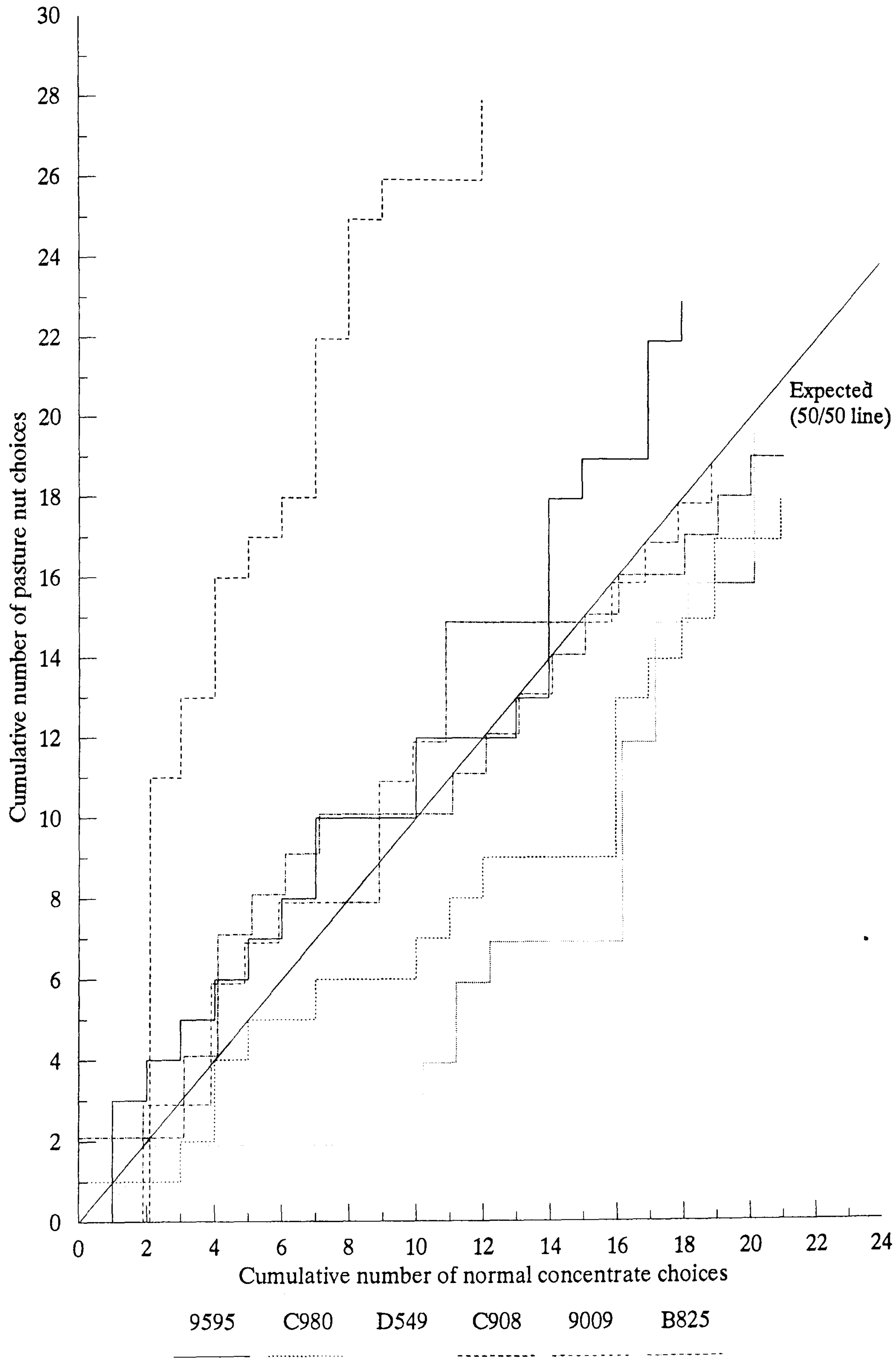


Figure 5.1b: Cumulative and sequential choices
for cows in experiment 1 part 2



3.2 Experiment 2 (Lit vs. dark)

The cumulative and sequential choices for each cow are shown in figure 5.2. The choices for the final twenty trials are shown in table 5.6. Cows 505 and 9590 missed the final eight trials. Cow 974 missed trials 47, 48 and 58.

Table 5.6 Number of correct and wrong choices for each cow over the last 20 trials in experiment 2. With Chi-square coefficient (d.f. = 1)

Cow	Correct choices	Wrong choices	Chi-square	Significance
276	14	6	3.2	n.s.
0028	13	7	1.8	n.s.
505	12	8	0.8	n.s.
974	17	3	9.8	p<1%
9590	8	12	0.8	n.s.
997	16	4	7.2	p<1%

Two cows (974 and 997) chose the correct spur highly significantly more than the wrong spur. The remaining four cows showed no significant preferences.

3.3 Experiment 3 (No signals)

The cumulative and sequential choices for each cow are shown in figure 5.3. The choices for the final twenty trials are shown in table 5.7. Cow 1146 missed trials 7-12 and cow 53 missed trials 13-24.

Table 5.7 Number of correct and wrong choices for each cow over the last 20 trials in experiment 3. With Chi-square coefficient (d.f. = 1)

Cow	Correct choices	Wrong choices	Chi-square	Significance
1033	9	11	0.2	n.s.
1146	9	11	0.2	n.s.
519	7	13	1.8	n.s.
527	12	8	0.8	n.s.
359	8	12	0.8	n.s.
53	9	11	0.2	n.s.

None of the cows chose the correct spur significantly more than the wrong spur.

The spur choices (left or right) for the final twenty trials are shown in table 5.8

Figure 5.2: Cumulative and sequential choices
for cows in experiment 2

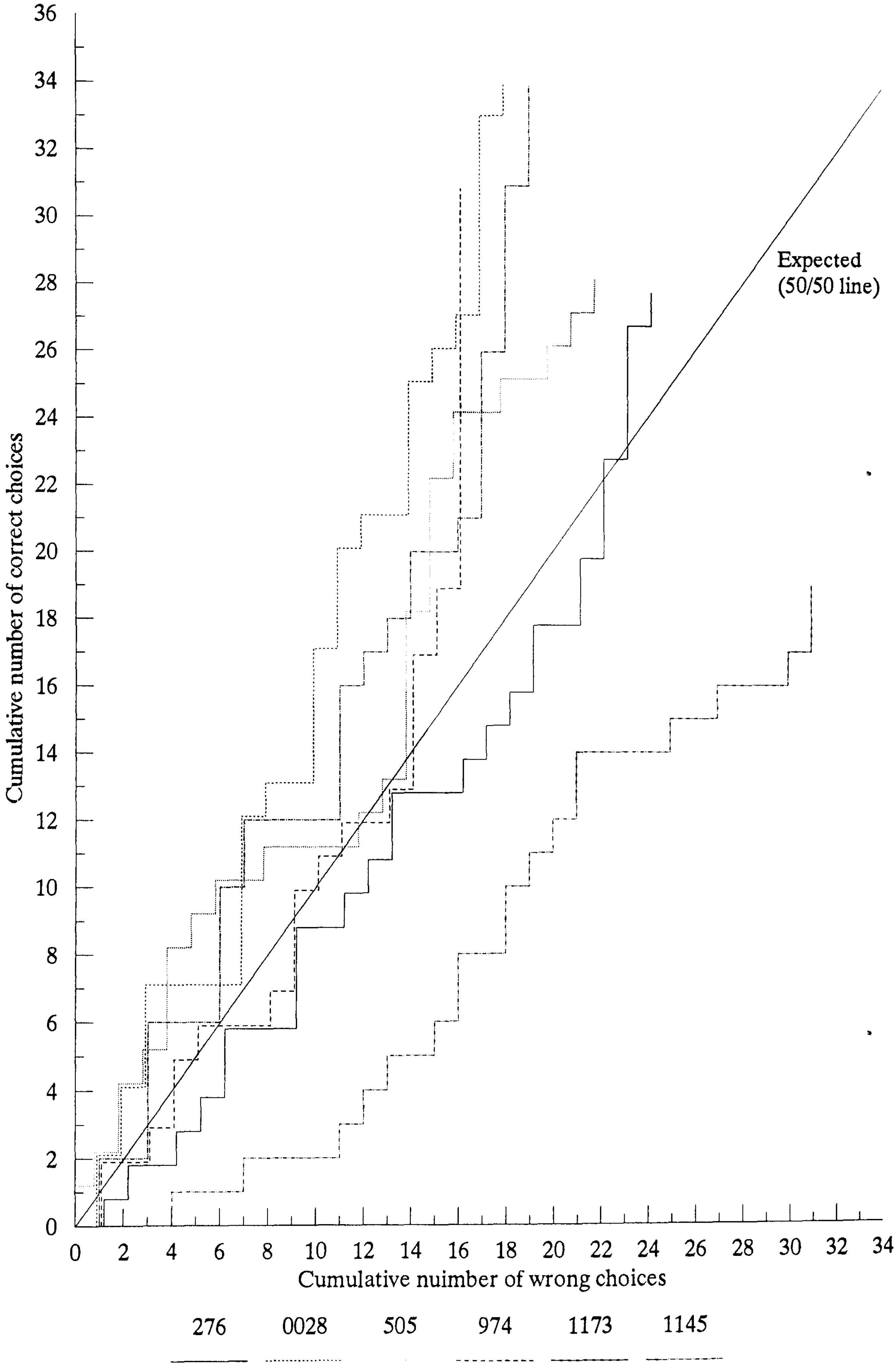


Figure 5.3: Cumulative and sequential choices
for cows in experiment 3

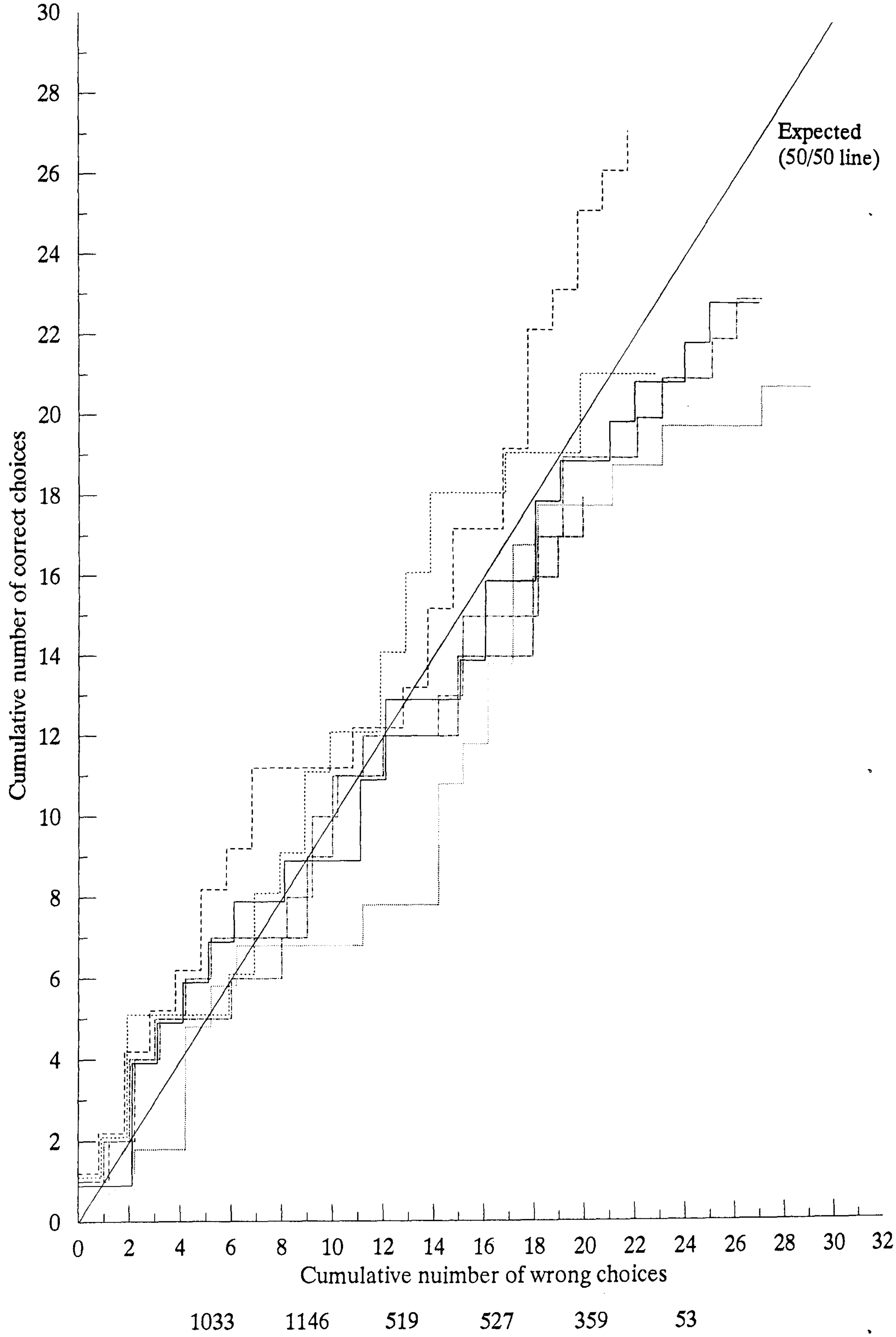


Table 5.8 Spur choices for each cow in the last 20 trials in experiment 3. With Chi-square coefficient (d.f. = 1)

Cow	Left spur choices	Right spur choices	Chi-square	Significance
1033	8	12	0.4	n.s.
1146	16	4	7.2	p<1%
519	14	6	3.2	n.s.
527	19	1	16.2	p<1%
359	19	1	16.2	p<1%
53	18	2	12.8	p<1%

Four of the six cows chose the left spur significantly more often than the right spur. Cows 519 and 1033 failed to choose either spur more than the other. The lateral choices for each cow were similar at the beginning of the experiment, the laterality choices for the first 20 trials are shown in table 5.9.

Table 5.9 Individual laterality choices for each cow in the first 20 trials in experiment 3. With the Chi-square coefficient (d.f. = 1)

Cow	Left spur choices	Right spur choices	Chi-square	Significance
1033	6	14	3.2	n.s.
1146	16	4	7.2	p<1%
519	15	5	5	p<5%
527	20	0	20	p<1%
359	20	0	20	p<1%
53	18	2	12.8	p<1%

4 Discussion

4.1 Experiment 1 (Red vs. yellow buckets)

The data for the first trial, where the cows had to differentiate between the red and yellow buckets containing different foods, showed that they failed to exhibit any clear preference for either of the pairs of foods

The reasons for the cows' general lack of response may have been because the reward was too weak a motivator. Chapter 3 experiment 2 showed that the cows could differentiate between the same two buckets if one contained food and the other did not. In the present experiment the lack of any signs of a significant preference suggests that the cows may not have learned because the difference in the reward value of either pair of foods was not great enough. Alternatively they may have learned what the signal indicated but the motivation continually to use a particular spur was stronger than the motivation to eat a particular food. Either way, this suggests that the difference in the cows' preference for either food was small. The cows' use of a particular spur would probably have been rewarding since not only would they be able to use their preferred spur, but also they would be fed their preferred food approximately half the time. The remainder of the time they would be fed a less preferred, but still palatable, food.

4.2 Experiment 2 (Lit vs. dark)

This experiment showed that only two cows seemed to understand the signal. These results are largely similar to those found in experiment 3 of chapter 3. This suggests that using a number of preferred foods randomly presented as the reward does not improve the cows' exhibition of learning. It is interesting that, even in the final 20 trials, the two cows who were showing strong signs of learning still tended occasionally to choose the wrong spur. This behaviour is difficult to explain. Presumably, these cows understood the signal but another factor influenced their response. They may have had some residual preference for one or other spur and occasionally the motivation to use this spur was stronger than the motivation to access the food spur. Alternatively, the cows may have been routinely exploring or sampling the `wrong' spur.

4.3 Experiment 3 (No signals)

This final experiment showed that when there was no signal in the maze, the cows failed to find the food and instead retained a strong preference for one or other spur. It also showed that the experimental protocol did not itself generate significant results due to the pattern of food presentation. This suggests that the significant data found in past experiments was due to the cows associating the signal with the reward. It also showed that, without any informative signal, the cows develop and retain a spur preference. They did not actively seek the food, for example, by going back to the spur they were last fed in, but continued to choose the same spur and approximately half the time they found food. If they had returned to the spur in which they were last fed they would have chosen the correct spur less often.

5 Conclusion

These experiments suggested that even with four randomly presented foods as the reward only some cows appeared to show signs of learning the signal. None of the cows who showed signs of learning did so infallibly. Some cows failed to show signs of learning the implications of the signals even after extended trialing. These data lead to the conclusion that training cows in the Y-maze to associate signals with food, so that this can be used in future preference tests, is not practical. The main failings of the method were that it failed to teach the cows quickly or consistently and even when they did learn they failed to choose the correct spur all the time.

When the cows were given no signals they tended to prefer to use a particular spur and showed no signs of choosing the food spur more often than they might at random.

CHAPTER 6

INFLUENCE OF STAGE OF LACTATION AND FEEDING ON DAIRY COWS' CHOICE TO BE MILKED

1 Introduction

This chapter explored the motivation of cows to be milked and how stage of lactation and feeding may have affected it. This may help our understanding of why cows may want to use an automatic milking system (AMS). Probably the most important reason cows attend the AMS is because they are fed in the system; either forage and/or concentrate. However, the cows may also derive some reward out of being milked either physically or psychologically. If cows exhibit a strong motivation to be milked then there may be no need to provide food rewards in the AMS.

Another reason for studying motivation to be milked is for reasons of welfare. If cows choose to be milked regularly, and therefore presumably derive some reward from being milked, it will further improve the suggested welfare advantages of the AMS. Especially if the cows choose to be milked more often than the conventional two times per day. Further to this, public perception of the AMS and dairy farming may be enhanced, since some of the public assume, based on little evidence, that cows do not like being milked (Robertson 1991, Thomson 1994, Prescott 1994).

There is no clear evidence of a motivation to be milked, and opinion among farmers, stock persons and dairy experts varies (Allen 1994, Walton 1994, Jolley 1994, Draycott 1994). Rathore (1982) suggested that the amount of milk in the udder affects motivation to be milked. Higher yielding cows would be expected to have a stronger motivation to be milked, to relieve the pressure in their udder, than lower yielding cows. This hypothesis was derived from the observation that high yielding cows tended to enter a parlour earlier than low yielding cows. Winter, in a similar experiment (1993), found no such significant effect, however there were trends in her data to support the observations of Rathore.

An alternative to the hypothesis proposed by Rathore (1982) is that cows may have some inherent psychological motivation to be milked, irrespective of the amount of milk in their udders but which changes with the stage of lactation. This would still agree with the observations of Rathore (1982).

Trivers (1974) suggested that parental investment in young, for cows this may predominantly be the provision of milk, should decline as the young mature and the mother starts to direct more of her resources to the *in utero* and future offspring. This eventually leads to weaning. Blass and Teicher (1980) proposed a mechanism for this theory suggesting that there are three stages in the development of suckling. In the first stage suckling is initiated by the mother. In the second stage suckling is initiated mutually by the mother and offspring. In the final stage suckling is initiated by the young. Boe (1993) provides evidence from sows and piglets which largely confirms this.

Bateson (1994) has challenged this view suggesting that the decision to wean may be mutual between the mother and her young. This is because the young may derive some benefit from having a mother in good physical condition after weaning, as opposed to one `worn out' by a prolonged lactation. Secondly the young may undergo physiological changes that require a change from milk to solid food, e.g. a maturing gut. Thirdly the young may not be able to meet their nutritional requirements solely from their mother's milk as they grow. The mother may also be prepared to change the weaning period if she is not pregnant or the lactation has been disrupted (Gomendio 1995).

During domestication cows have been bred for ease of milking, especially ease of let-down. Moreover the increase in yields and the artificial system of twice a day milking has resulted in cows hypertrophic udders (Webster 1995). It is also clear that the level of stimulation needed to facilitate the let-down process in *Bos taurus* cows is lower than that needed for *Bos indicus* cattle (Phillips 1993). This may imply that *Bos taurus* cows find machine milking closer to natural suckling than *Bos indicus* cows and therefore may find it more reinforcing. If udder fill is important in motivation to be milked then the increased size of modern dairy breeds' udders may increase the amount of milk needed in the udder to cause it to become uncomfortable.

This chapter describes three experiments performed in the Y-maze assessing the motivation of cows to be milked. The first experiment gave early lactation (high yielding) cows the choice between being milked or not being milked at short intervals. If the cows opted for short inter-milking periods then it suggests that the cows derive some reward from milking other than simply the relief of udder weight and pressure, since there will be little milk in the udder. Knight et al. (1994) showed that high yielding cows secrete milk at a constant rate of approximately 1kg/hour over a period of 12 hours. In this experiment the cows were given the choice to be milked at 3.5 hour intervals, if they chose to be milked at this interval it would imply a moderate milk yield of 3.5kg.

The second experiment assessed late lactation (low yielding) cows' motivation to be milked over the same short inter-milking periods. Knight et al. (1994) showed that the secretion rate of late lactation cows is approximately half that of early lactation cows. Therefore if they chose to be milked every 3.5 hours, their yield should not have exceeded 1.75kg.

The final experiment looked at early lactations cows' choice between either being milked or fed. Since it can be presumed that the motivation for cows to eat concentrate is high then this provides a benchmark with which to compare the motivation to be milked.

Therefore the aims of these experiments were four-fold. First, to determine if cows are motivated to be milked for physical or psychological reasons. Secondly, to determine if motivation to be milked declines as lactation progresses. Thirdly, to determine the relative strengths of motivation to be milked versus motivation to be fed. And finally, to determine if motivation to be milked is likely to attract cows to the AMS at an appropriate frequency.

2 Materials and Method

2.1 The maze

The maze has been described in chapter 2

2.2 The milking apparatus

The milking apparatus consisted of two bucket milkers positioned either side of the maze at the end of each spur, (see figure 6.1a). A vacuum pump was connected to each bucket milker and produced a vacuum level of 50kpa at the connection point with each bucket milker. From each bucket milker the long pulse and milk tubes terminated in the cluster. The cluster used a standard Alfa-Laval bowl (Alfa-Laval Ltd. Oakfield road, Cwmbran, Gwent) connected to the appropriate standard Alfa-Laval shells and liners. Each bucket milker had independent pulsation generated by Alfa-Laval vacuum driven 'Hydropulse' pulsators which provided alternate pulsation (or 2 *X* 2 pulsation, Akam and Spencer 1992). These pulsators delivered a pulsation rate of 55 and 58 pulses per minute for the left and right milker respectively. (The age of the pulsators probably contributed to the small difference in pulsation rate). The clusters, vacuum level and pulsation rate were similar to those found in the farm's main parlour and to which the cows were accustomed.

Each milker consisted of a lid, to which all the tubes and pulsators were connected, and a 45l (standard 10 gallon) churn. The long milk tube of each milker contained an Ambic mastitis detection filter (Ambic Equipment Ltd. Witney, Oxford). A diagram and photograph of one of the milkers is shown in figures 6.1b and c.

To access the cow's udder, a lower portion of each side of the maze was cut away and hinged, providing a flap which could be opened or closed. Holes were also cut into the side of the maze so a bar could be placed behind the cow to prevent her reversing out of the spur while being milked.

Figure 6.1a: Position of bucket milkers in the Y-maze

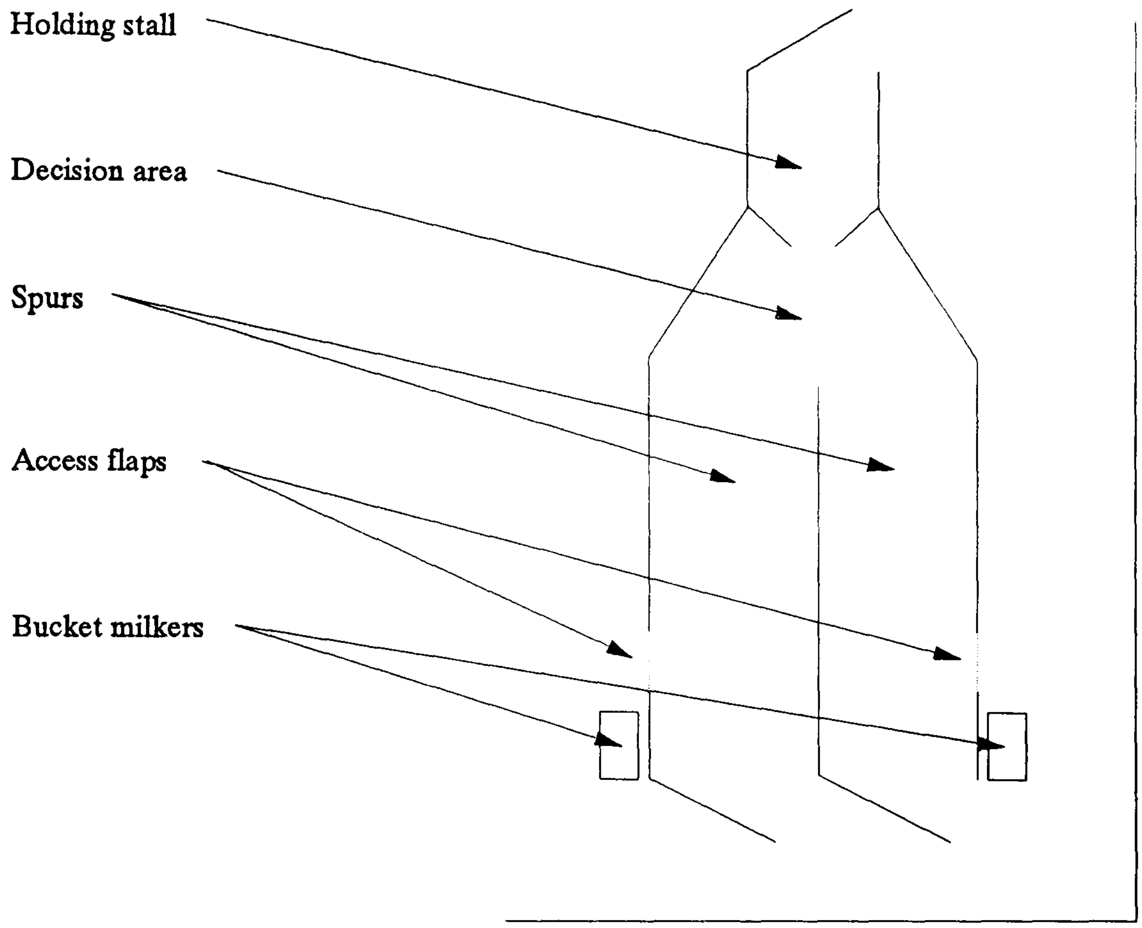
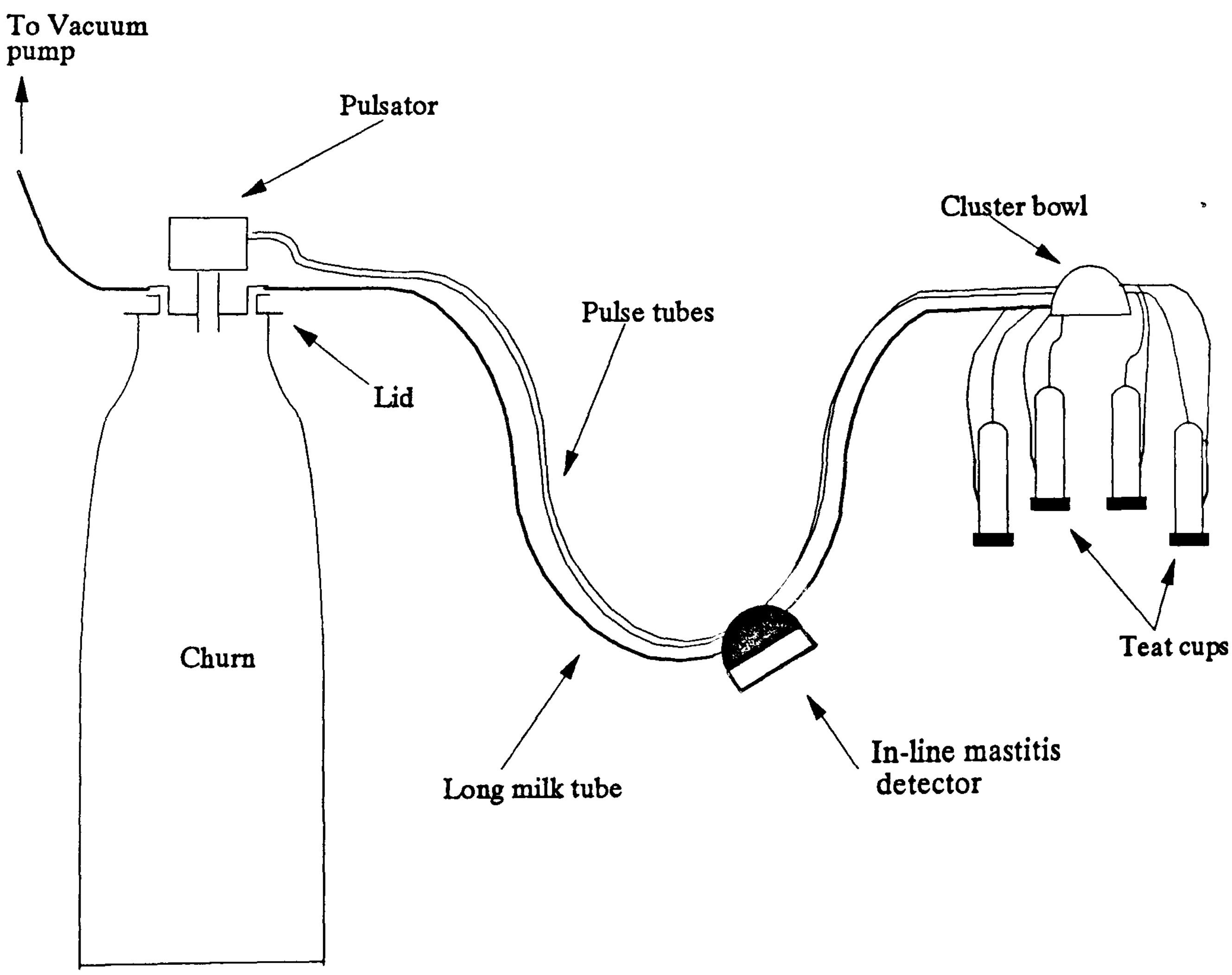


Figure 6.1b: Diagram of bucket milker



2.3 General method

During the experiments the cows were permanently housed in the shed that contained the maze. They had *ad lib.* access to forage (for details see chapter 2), which provided adequate nutrition for maintenance plus 20 l of milk, and was delivered fresh every day. The cows were supplemented with dairy cow concentrate (BOCM/Pauls, for details see appendix 4), at an appropriate rate for their individual level of production. They also had access to six cubicles surfaced with cubicle mats and sawdust (which was replenished daily), water drinkers and a small concrete yard.

During the experiments the cows were herded into the collecting ring at specified times and allowed through the maze individually. If they did not choose the milking spur, they were allowed to return to the living area. If they did choose the milking spur, the exit door at the end of the spur was locked shut and a bar positioned behind the cow, preventing her leaving the spur either forwards or backwards. When the cow had been restrained, the flap in the side of the maze was opened and the cow's teats cleaned with medicated teat wipes (Genus Ltd. Westmere Drive, Crewe). Immediately following this the teat cups were attached and the cow milked (see figure 6.1d). When the cow had finished milking, the teat cups were removed manually, her teats dipped in a proprietary teat dip, and then she was let out and free to return to the living area via the return race. The next cow was then allowed into the decision area and given the same choice. The cows were free to enter the holding stall in any order.

In each of the three experiments detailed below the cows were trialed through the maze every 3.5 hours five times per day. For the first experiment the times at which each trial started were 07:00, 10:30, 14:00, 17:30 and 21:00. For the remaining two experiments each trial started one hour earlier. The cows were milked a minimum of two times per day, If any cow failed to choose to be milked at either of the first two trials she was milked, after being allowed a voluntary choice, at the second milking. If she had not chosen to be milked at the third, fourth or fifth milking she was made to be milked, after an initial voluntary choice, at the fifth milking. Equally if a cow had chosen to be milked at the first, second, third and fourth milking, she was made to use the non-milking spur at the fourth trial, after an initial voluntary choice (this was to help prevent the generation of a preference for one side of the maze, as discussed in the introduction of chapter 3). Therefore a cow who never chose to be milked would have had (enforced) milking

Figure 6.1c: Photograph of bucket milker

Figure 6.1d: Photograph showing the author attaching the teat cups

intervals of approximately 13.5 hours overnight and 10.5 hours during the day.

2.4 General Experimental design

Each experiment followed a similar design. Six cows were divided into two groups. Group 1 was trained to associate one side of the maze with one treatment and the other with the other treatment. Group 2 was similarly trained but with the treatments reversed between the spurs. The cows were then allowed to choose between the treatments five times per day for nine days. The treatments were then swopped between the spurs for each group, the cows retrained and the experiment continued for a further nine days with five trials per day (see table 6.3).

2.5 The cows

Details of the cows are shown in the table below for each experiment, experiment 2 used three cows from experiment 1. DIM indicates days in milk.

Table 6.1 Details of individual cows used

Cow	Experiment	Parity	Yield (l)	DIM
202	1	6	34.2	157
367	1	7	35.9	130
830	1	5	38.9	116
373	1	2	39.0	107
568	1	3	30.5	95
142	1	2	25.0	170
568	2	3	13.5	254
562	2	2	12.7	272
830	2	5	12.2	275
373	2	2	16.2	266
366	2	2	15.3	246
239	2	3	13.0	269
345	3	4	37.4	109
674	3	3	34.8	136
978	3	4	38.1	97
478	3	2	35.6	140
290	3	2	29.3	154
528	3	5	35.9	137

Table 6.2 Means for the cows on each experiment

Experiment	Parity	Yield (l)	DIM
1 (sd)	4.2 (2.1)	33.9 (5.4)	129 (29.2)
2 (sd)	2.8 (1.5)	13.8 (1.6)	264 (11.3)
3 (sd)	3.3 (1.2)	35.2 (3.1)	129 (21.4)

This table shows that each group had similar mean parities, but the cows in experiment 2 had lower yields and a greater number of DIM.

Besides yield, the cows were selected for being quiet and with sound hooves; heifers were not selected.

2.6 General training method

Each experiment involved two similar training periods each three days long, the first at the beginning, and the next midway through, the experiment. A training day consisted of the cows being milked three times per day in the appropriate spur at the first, third and fifth trial session. At the second and fourth trial sessions the cows were made to use the non-milking spur. This was to ensure that the cows had experience of both treatments.

2.7 The treatments

Table 6.3 shows a summary of the treatments.

Table 6.3 Design for both halves of each of the three experiments showing the treatments down each spur (L=left spur, R=right spur), and the members of each group in each experiment

Experiment	Group/Cow	1st half of experiment	2nd half of experiment
1	Gp1 367, 373, 568	milk=L/nothing=R	milk=R/nothing=L
	Gp2 830, 202, 142	milk=R/nothing=L	milk=L/nothing=R
2	Gp1 830, 366,562	milk=L/nothing=R	milk=R/nothing=L
	Gp2 373, 568, 239	milk=R/nothing=L	milk=L/nothing=R
3	Gp1 345, 674, 978	milk=L/fed=R	milk=R/fed=L
	Gp2 478, 290, 528	milk=R/fed=L	milk=L/fed=R

2.7.1 Experiment 1 (Milk vs. nothing, high yielders)

This experiment gave six high yielding cows the choice between being milked or not.

The first half of the experiment only consisted of eight days (due to the author's ill health), but the second continued for nine days.

Two cows, 373 and 568, contracted mastitis in the second half of the experiment, they were treated in the recommended manner with the antibiotic `tubes' administered in the cubicles not in the maze (to prevent the cows from associating the maze with negative consequences). Neither cow appeared alarmed by the procedure.

2.7.2 Experiment 2 (Milk vs. nothing, low yielders)

This experiment was the same as the previous experiment. However, the cows were on average 135 days later in lactation and yielding less than half the amount of milk. It was intended to use the same cows in this experiment as were used in the last experiment, but at a later stage of lactation. By the time the cows were in late lactation, however, 202 was chronically lame, 142 had been dried off and 367 had mastitis.

2.7.3 Experiment 3 (Milk vs. food, high yielders)

This experiment gave the cows the choice of being milked or receiving $^1/_3$kg of food in a large (10 l) grey plastic bucket. The food was one of the four preferred foods derived from the food preference test described in chapter 4. These foods were the cows' normal pelleted concentrate, pasture nuts (a pelleted feed usually fed to sheep), coarse ration (a non-pelleted mix designed for very young stock), and soaked sugar beet pellets with added sugar, details of these foods can be found in appendix 4. The random order of presentation was the same as that described in the method for experiment 2 in chapter 5.

2.8 Statistical analysis

Since the same cows were not used across the three experiments, the Wilcoxon matched pairs test could not be used to compare results across the experiments. Instead trends in the data for each experiment with time (i.e. cows increasingly or decreasingly choosing to be milked, as a group) were assessed using the Spearman's rank test. The difference in the number of milkings between the high and low yielding groups was analysed using the Mann-Whitney U test.

3 Results

3.1 Experiment 1 (Milking vs. nothing, high yielders)

Table 6.4 shows the number of milkings chosen by each cow and the total for each day of the experiment.

Table 6.4 Number of milkings chosen by each cow during each half of experiment 1

Cow	367	373	568	830	202	142	Total
1st half:							
day 1	2	0	0	5	0	5	12
2	5	2	0	5	0	5	17
3	5	3	0	5	0	5	18
4	5	5	0	5	0	5	20
5	5	4	0	5	3	5	22
6	5	3	0	5	3	5	21
7	5	5	0	5	5	5	25
8	5	5	0	5	5	5	25
Total	37	27	0	40	16	40	160
2nd half:							
day 1	0	0	2	1	0	0	3
2	0	1	1	1	0	0	3
3	0	0	0	0	0	0	0
4	0	0	0	1	1	0	2
5	0	1	0	0	0	0	1
6	4	0	0	5	3	0	12
7	5	1	0	5	5	0	16
8	4	0	0	5	2	0	11
9	5	5	0	5	4	2	21
Total	18	8	3	22	15	2	69

Three of the cows (367, 830 and 202) preferred being milked, following the treatment as it was swopped between the spurs. Of the remaining cows, 568 was averse to being milked, indeed she often tried to kick during attachment although not during milking. Outside the milking spur she appeared calm and sometimes solicited attention. Cow 373 chose to be milked in the first half of the experiment but not in the second half until the final day when she chose to be milked at all opportunities. Cow 142 showed an initial preference for the milking spur. However when the treatments were swopped between the spurs she continued to choose the same, now non-milking, spur.

The total number of milkings (summed from all the cows) for each day are plotted in figure 6.2. The curves show that in each half of the experiment the cows increasingly chose the milking spur. The Spearman's rank correlation coefficient and significance of these curves are shown in table 6.5.

Table 6.5 Spearman's rank correlation coefficient and significance for each half of experiment 1

	Spearman's rank correlation coefficient	Significance
1st Half (n=8)	0.98	p<1%
2nd Half (n=9)	0.68	p<5%

The trends in the data were significant, as the experiment progressed, the cows, as a group, chose to be milked more often.

3.2 Experiment 2 (Milking vs nothing, low yielders)

Table 6.6 shows the number of milkings chosen by each cow for each day of the experiment.

Table 6.6 Number of milkings chosen by each cow during each half of experiment 2

Cow	568	562	830	373	366	239	Total
1st half:							
day 1	2	0	4	5	0	5	16
2	0	2	2	5	0	5	14
3	0	5	4	5	0	5	19
4	0	5	4	5	0	5	19
5	0	5	2	5	0	2	14
6	0	5	2	4	0	0	11
7	0	5	2	5	0	1	13
8	0	4	3	4	0	1	12
9	1	3	3	5	0	0	12
Total	3	34	26	43	0	24	130
2nd half:							
day 1	4	4	0	0	5	0	13
2	3	5	0	1	5	0	14
3	0	4	0	0	4	0	8
4	0	4	0	0	3	1	8
5	0	4	0	2	0	0	6
6	0	4	4	1	0	1	10
7	1	5	5	1	0	2	14
8	1	4	5	2	0	1	13
9	1	3	5	4	0	0	13
Total	10	37	19	11	17	5	99

Some cows (562, 830, 373) exhibited some motivation to be milked. Three cows, 568, 366 and 239, seemed to try to avoid being milked. No cows preferred one or other spur irrespective of the treatments. The three cows common to both experiments showed similar results in each, 568 continued to be aversive to being milked, while 373 and 830 retained some apparent motivation to be milked. The total number of milkings chosen by the cows are plotted in figure 6.2, contrasted with the data from experiment 1. The Spearman's rank correlation data for this experiment are shown in table 6.7.

Table 6.7 Spearman's rank correlation coefficient and significance for each half of experiment 2

	Spearman's rank correlation coefficient	Significance
1st Half (n=9)	-0.71	$p<5\%$
2nd Half (n=9)	0.13	n.s.

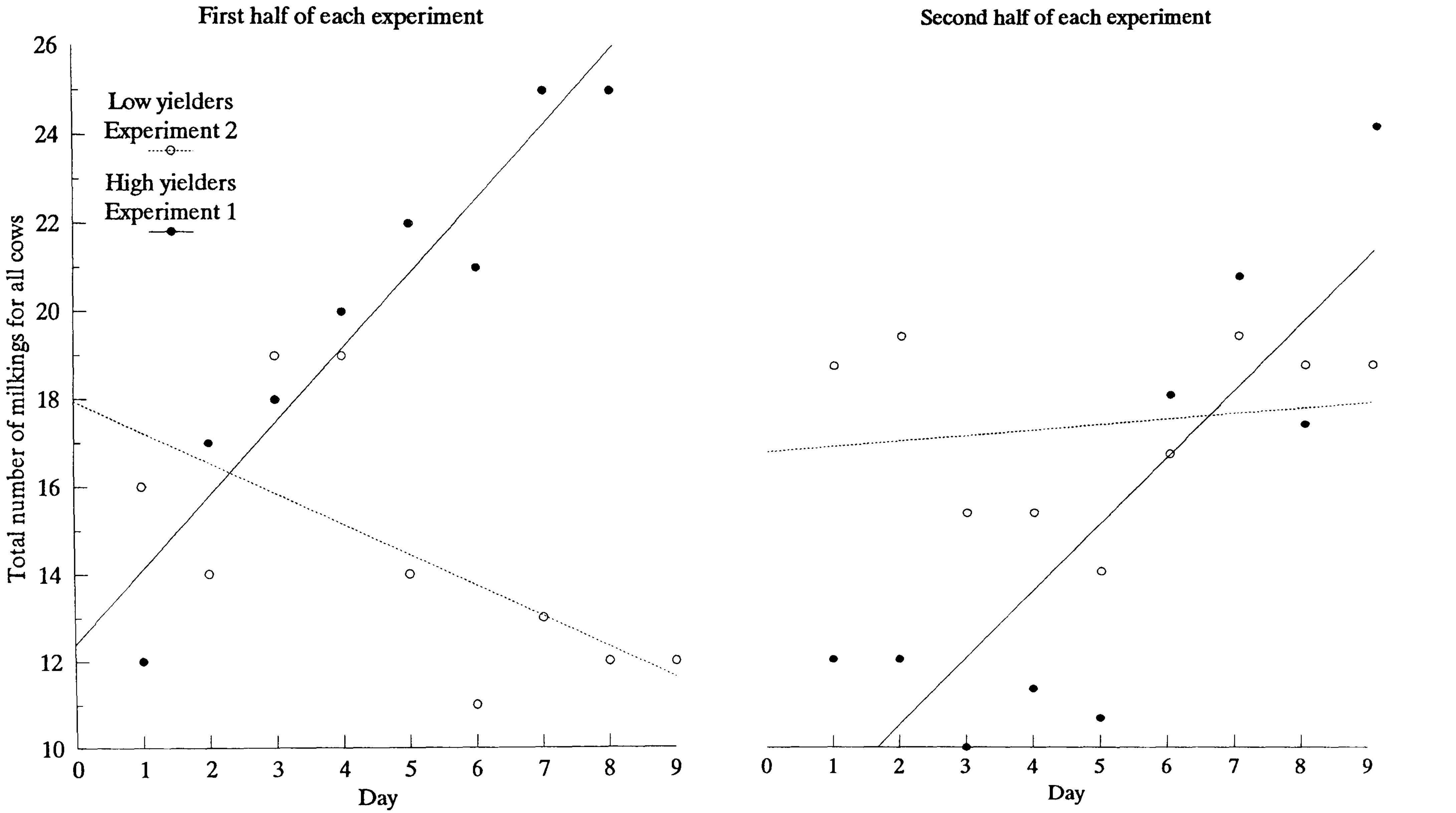
During the first half of the experiment the cows, as a group, significantly reduced the number of times they chose to be milked. In the second half of the experiment there was no such trend.

When the milkings for each cow were summed for each half of each experiment, there was no difference between the number of milkings for the high or low yielders ($p>5\%$ Mann-Whitney U test, n_1 and $n_2=6$)

3.3 Experiment 3 (milking vs. food)

In this experiment all the cows chose the food spur at every opportunity, no cow ever chose to be milked.

Fig. 6.2: Total no. of choices to be milked (vs nothing) in experiments 1 and 2



4 Discussion

4.1 Experiment 1 (Milk vs. nothing, high yielders)

At the group level this experiment showed that the high yielding cows exhibited signs of a motivation to be milked. At the individual level this was not quite so clear. One cow was very nervous of the whole procedure and sought to avoid the milking spur. When the treatments were swopped between the spurs, she appeared to learn the new positions of the treatments very quickly. In the first two days of the second half of the experiment she only chose to be milked three times. Compared with the response of the cows that eventually chose to be milked, this was much quicker. If speed of learning is broadly correlated to strength of motivation then this cow was highly motivated to avoid the spur that contained the active milker. It is interesting to note that the cows who did show some preference for being milked appeared to take four or five days, or 20-25 trials, to re-associate the treatments with the spurs. This was not so evident in the first half, suggesting that it may be difficult for the cows to `unlearn' something which they have already learned. Clearly, the second training period did not prepare the cows for the choices they had to make, perhaps they needed to learn by trial and error. One cow (142) showed a stronger motivation to continue using the same spur than to be milked which, along with the slow re-learning, suggests that motivation to be milked may be quite weak.

This experiment also suggests that any motivation to be milked cannot be explained solely by the cows wanting to relieve a large and distended udder. In this experiment those cows who attended every 3.5 hours would have had an insignificant amount of milk in their udders (and the author observed that their udders appeared flaccid). Although this was not directly recorded a secretion rate of 1kg of milk/hour (Knight et al. 1994) would amount to approximately 3.5l, a small yield of milk when it is considered that these cows can yield 20-25l at one milking.

4.2 Experiment 2 (Milk vs. nothing, low yielders

The low yielding cows did not appear to choose to be milked as often as the high yielding cows had. None of the cows attempted to be milked as often as possible, and three positively tried to avoid the milking spur, 568 showed a similar response in experiment 1. No cow showed a motivation to use one spur that was stronger than that generated by the treatments. This apparently more variable response to that seen in the last experiment may arise from two sources, either it is a function of the stage of lactation or it is a function of the small sample size.

4.3 Experiment 3 (milk vs. fed, high yielders)

This experiment showed that the cows were more strongly motivated to choose the food bearing rather than the milking spur. The speed at which they learned is another indication of this. In experiment 1 the cows who appeared motivated to be milked took 20-25 trials to re-learn the location of the milking spur in part 2 of the experiment. In this experiment none of the cows ever chose the milking spur even directly after the swop.

4.4 General discussion

These experiments suggest that the strength of motivation to be milked varies between cows, and there is little evidence to suggest that the stage of lactation affects this. Udder fill seems to be unimportant, since most of the high yielders and some low yielders chose to be milked at the minimum milking interval of 3½ hours. At this interval there will have been little milk in the udder. The cows may therefore either be deriving some physical reward from being milked (e.g. tactile stimulation of the teats or the oxytocin release during let-down), or some psychological reward, for example they may associate the milking process with feeding a calf. There is little evidence to support Trivers' weaning theory (1994) which suggests that late lactation cows may choose to be milked less often than early lactation cows. The variability in the motivation to be milked suggests that some cows may find being milked negatively reinforcing whereas for other cows milking may be positively reinforcing.

Motivation to be milked seemed weak, and there are three reasons for suggesting this. First, the cows took a comparatively long time to show evidence of learning an apparently simple response even after a training period. Secondly, the cows exhibited a high degree of variability. While this does not exclude the possibility that some cows found milking highly motivating, it does tend to suggest that the motivation is weak. Finally, the fact that the cows showed a strong motivation to choose a small food reward over milking (and learn that quickly and universally) tends to suggest that motivation to be milked is significantly less motivating.

There are three important limitations of these experiments. First the experiments were only run over a short period (each half 8-9 days), perhaps if the experimental periods were longer the picture of milking motivation may have been clearer. Secondly, the experiments used cows who had experience of twice a day milking. This may have affected how they responded when given the milking choices. Finally, only a small number of cows were used.

Overall it can be suggested that in the AMS some cows may attend because they derive some reward from being milked. However, it is unlikely that attendance could be driven solely by motivation to be milked due to the variability exhibited by the cows. The evidence from experiment three suggests that the provision of food in the AMS may be a more practical method of generating frequent attendance.

5 Conclusions

Some high yielding cows showed a consistent motivation to be milked, while none of the low yielding cows did. As a group the number of milkings chosen rose significantly for the high yielders in both halves of the experiment. This was not so for the low yielders, who significantly reduced the number of milking choices in the first half of experiment 2. When high yielding cows were given the choice between being milked or fed they always chose to be fed suggesting that motivation to be milked is weaker than motivation to be fed.

In general it is unlikely that motivation to be milked could generate adequate attendance (3+ times/day) to the AMS. Food however, may be able to.

CHAPTER 7

ASSESSING RANK AND FEARFULNESS IN A SMALL GROUP OF DAIRY COWS

1 Introduction

Rank order in a group of cattle can be defined as the sum of agonistic interactions between all pairs, or `dyads', of animals (Beilharz and Zeeb 1982). Cows of high rank dominate most other cows whereas cows of low rank dominate few animals. Rank order may affect how often and in what order the cows enter the AMS, since the food reward provided in the AMS may create competition to enter. Thus higher and lower ranking cows may get more and less access to the AMS respectively, than average.

In any dyad, one or both cows may try to dominate the other by fighting. Some agonistic interactions however, may be very subtle since a very low ranking animal may avoid contact with a high ranking cow. The only evidence of this sort of relationship may be a lack of social interaction of any kind. Between these two extremes lie agonistic behaviours such as threatening and submissive postures. Various agonistic behaviours were pictorially represented in Dickson et al. (1966). Rank order in cattle probably serves to reduce the level of aggression within a group, since each cow will know her rank relative to each of the other group members, avoiding the need for outright aggression (Phillips 1993, Beilharz and Zeeb 1982, Hughes 1977c). Rank has not been consistently correlated with measures of size, age or production level (Arave et al. 1975, Beilharz and Mylrea 1963, Dickson et al. 1966, Miller and Wood-gush 1991, Collis 1976, Beilharz et al. 1966, Beilharz and Zeeb 1982, Dickson et al. 1970). This may be because rank has a degree of inertia. Cow A may be expected to be of higher rank than cow B but fail actually to be so because of some historical factor. For example she may have been severely bullied by cow B when she first entered the herd as a heifer, and is disproportionally frightened of her. This may contribute to `non-linear' orders where cow A is dominant to cow B who is dominant to cow C who is in turn dominant to cow A. These were termed circular relationships (Appleby 1983) or reverse bunting (Beilharz and Mylrea 1963).

Methods of calculating rank orders often rely on observations of cattle over long periods (Miller and Wood-Gush 1991, Hinch et al. 1982, Arnold and Grassia 1982, Dickson et al. 1966, Schein and Fohrman 1955, Beilharz and Mylrea 1963, Collis 1976, Beilharz and Mylrea 1963, Beilharz et al. 1966, Bouissou and Signoret 1971, Arave et al. 1975, Beilharz and Zeeb 1982, Dickson et al. 1970). This method was time consuming and may not have detected all interactions, for example between very low and very high ranking cows. The method also relied on subjective analysis of subtle agonistic behaviour. Mistaken identity, when viewing cows from far away. and mistakes in recording during intense agonistic activity were reported (Schein and Fohrman 1955, Beilharz and Mylrea 1963). The method did, however, allow some quantification of the dominance of each cow, often called the `dominance value' (Beilharz and Mylrea 1963). Other methods for determining rank orders have involved analysing feeding behaviour, for example replacement rate at a feed barrier (Anon. 1992, Arnold and Grassia 1982, Rutter et al. 1987). Jensen (1982) showed the existence of an `avoidance' order, where it was supposed that low ranking sows avoided more sows than did higher ranking sows.

Soffie et al. (1976) used a food competition test. They placed two food containers at different points in a loose housing barn, where all cows could feed from them, and then recorded agonistic interactions between the cows as they competed for access to the containers. Brouns and Edwards (1994) used a similar food competition test with sows. Instead of allowing all sows access to a food reward however, they selected all possible dyads from a group and made each dyad compete for a single food reward. Whichever sow `won' the food reward was deemed to be higher ranking in the dyad. The results from this test agreed well with those obtained from conventionally observed agonistic behaviour, suggesting that agonistic rank orders related to food represent rank orders generally.

The rank determination part of this chapter used the food competition test of Brouns and Edwards (1994) to determine the rank order of 14 dairy cows.

One important aspect for the development of the AMS is `fearfulness'. Fearful cows may be less willing to use the system than `bold' cows if they find it threatening. Once in the system fearful cows may move through the system slower and behave differently in the milking stall than bolder cows.

Kilgour (1975) used an open field test to assess the `emotionality' of cattle. Cows were allowed into a 22m^2 arena and their movement around the arena measured from a grid painted on the floor. In addition, two experienced dairy technicians subjectively rated the cows on temperament. The results showed that the technicians did not agree with each other, and that the interpretation of the ambulation scores was difficult, even regarding whether high ambulation scores related to `calm' or `flighty' temperament. Kovalcikova and Kovalcik (1982) used a similar method, trying to correlate milk production with ambulation; young cows showed some correlation but older cows did not. Dellmeier et al. (1990) found that housing affected calves' performance in an open-field test. Calves kept in close confinement showed greater locomotory behaviour. Tulloh (1961) studied cattle behaviour in entering a crush as a measure of temperament and found that there were significant breed effects. In Tulloh's study, temperament was divided into six categories; docile, slightly restless, restless, nervous, wild and aggressive. These were subjectively 'scored' by observers.

MacKay and Wood-Gush (1980) suggested that an animal's reaction to a novel situation was a combination of curiosity to explore and neophobia. In the AMS visits made out of curiosity may rapidly decrease since the system design and functioning varies little from visit to visit. Fear of the system may remain high for fearful cows, especially if fearful cows do not use the system as often as bold animals. Thus measures that include aspects of curiosity in determining temperament, for example the open field test, may not be relevant in this situation.

This experiment tested a novel method for determining `fearfulness'. Cows were required to negotiate a novel stimulus to reach a food reward. The number of `tries' the cows needed to negotiate the stimulus, within a defined time, was the measure of fearfulness.

The aim of this chapter was to determine the rank order and fearfulness for a small group of dairy cows in novel ways, and to correlate the rank, fearfulness and age.

The cows studied in this experiment were the same as those in chapters 8, 9 and 10. The measures of fearfulness and rank determined here were therefore used in the proceeding chapters.

2 Materials and Method

2.1 Assessing Rank

A pair of cows were presented with a single bucket containing concentrate (BOCM/Pauls 1592 Dairy Nuts, for details see appendix 4) behind the feed barrier in the exit area of the AMS. The cows then competed for the food. A cow was considered to be of higher rank than her pair if she managed to head butt (Dickson et al. 1966) the feeding cow on the flank or the feeding cow withdrew before the head butt occurred. The bucket was then given to the lower ranking cow (if she could get to it) to repeat the effect. The bucket was too small for both cows to get their heads into it simultaneously, and deep enough so that most of the feeding cow's head was protected. Thus, the most effective way to oust a cow from the bucket was to head butt her (a fight sequence is shown in figures 7.2a, b and c). Every possible dyad was tested in this manner. After drawing up a provisional best-fit ranking based on the number of `wins', the procedure was repeated for all the cows. Nonlinear relationships were only deemed proven if they occurred in both trials, otherwise they were ignored.

2.2 Assessing Fearfulness

Fearfulness was assessed, after the rank determination, on the same cows. Three novel stimuli were introduced into the milking stall, past which the cows had to walk to receive $^{1}/_{3}$kg of food reward in the feed trough (for the order and food types see experiment 2 in chapter 5). The time taken for the cows to walk from the cleaning race to the feed bowl (see figure 2.2a, chapter 2) was recorded. The cows were repeatedly tested until they learned to walk past the stimulus and to the feed trough in under 15s; a reasonable time for the task since the distance was only 4m. The number of attempts needed by an individual cow needed to pass the stimulus was used as a measure of her fearfulness.

The first stimulus was a balloon hanging from the top of the milking stall, the bottom of which was 100cm off the floor of the stall. A small amount of water was introduced into the balloon before inflation to ensure that it hung vertically. The cows could not reach the food trough without pushing the balloon out of the way. The second stimulus was a rag hanging in the same position but doused in brandy essence (Supercook, Sherburn-in-Elmet, Leeds). The third stimulus was randomly selected passages of a Mozart piano concerto (K271) played through two speakers positioned above the milking stall. This procedure ensured that the cows were tested using a novel visual, olfactory and auditory signal.

All the cows had experience of the AMS prior to this assessment.

2.3 The animals

The cows were selected from the herd at Cheseridge, the Institute for Animal Health's dairy farm. Details of these animals are given in tables 7.1 (where DIM indicates days in milk).

Table 7.1 Cow Data

Cow	Yield (l)	Parity	DIM
29	23.5	3	188
44	20.1	2	207
81	24.4	3	126
123	23.8	3	132
335	21.9	9	171
533	26.0	4	126
815	25.1	6	132
1035	23.3	2	137
1067	20.2	2	127
1107	24.5	2	131
1118	22.2	2	172
1376	21.2	1	186
2006	24.2	1	173
2050	20.0	1	190

3 Results

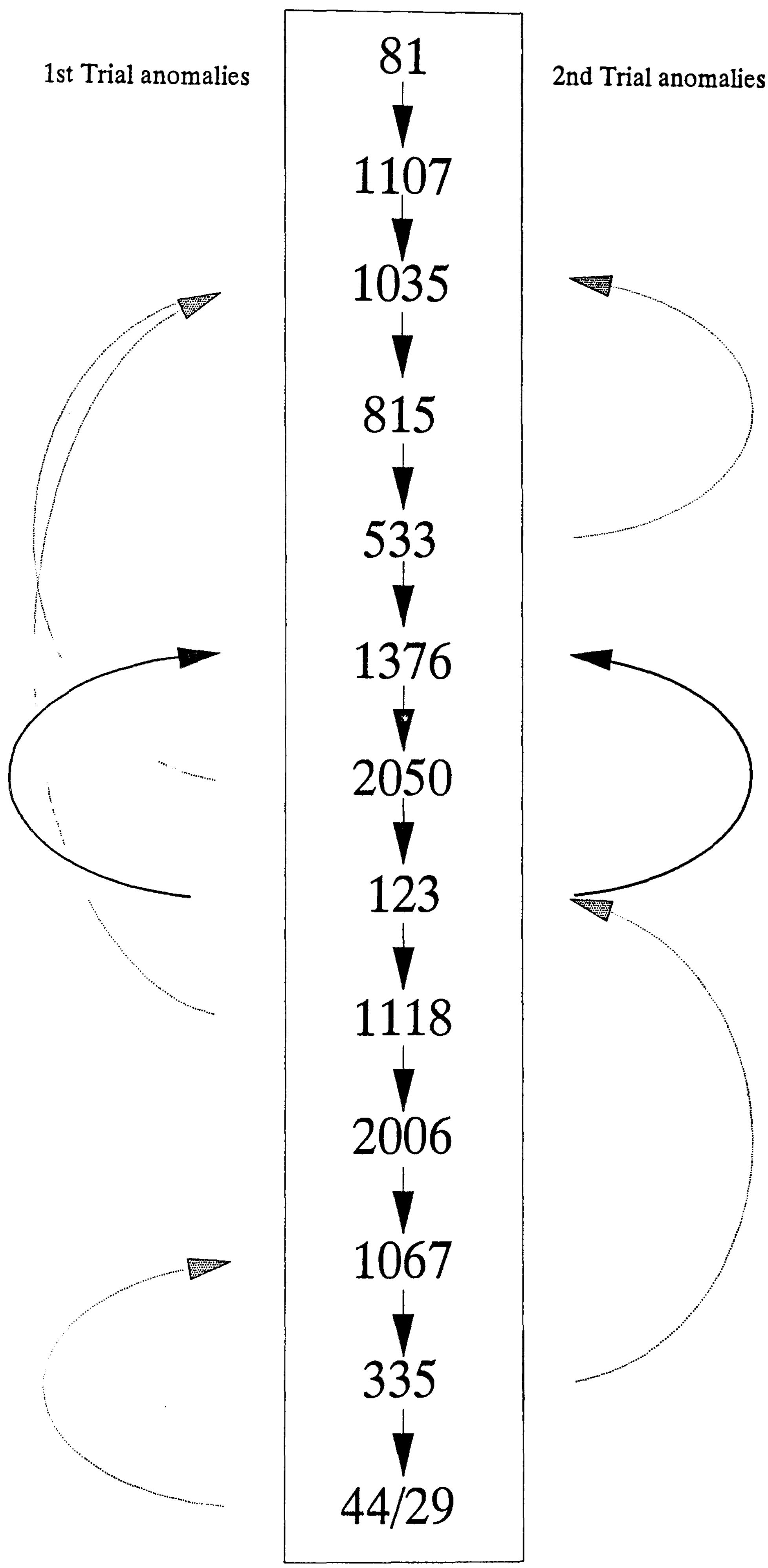
3.1 Assessing Rank

The best-fit rankings for each trial are shown in figure 7.1. The central portion of this figure shows the best-fit ranking. The curved arrows to the left of this relate to circular relationships found in the first trial, whereas the arrows to the right relate to circular relationships found in the second trial. The sequence of photographs shown in figure 7.2 a,b and c show a typical aggressive interaction between two cows (81 the winner and 1107 the loser). The rank order was initially arrived at by ordering the cows by the number of `wins' or `losses'. Where cows had the same number of wins or losses, their particular dyad test was used to rank them. This effectively gave a `best fit' order. In the first order there appeared to be four circular relationships. In the second trial the best-fit ranking was identical to the first trial with three apparently circular relationships, one of which was the same as in the first trial. Only the one common circular relationship between cows 1376, 2050 and 123 was deemed to be true (shown as a black arrow in figure 7.1). Some cows seemed reluctant to challenge other cows, this was particularly true of 1035 and 29. They did, however, provide enough data to imply a rank position based on the positions of the cows which they did challenge. Cows 44 and 29 never challenged each other and always lost other challenges (44 did make one successful challenge against 1067 but this was an apparent triangular relationship which was not supported in the other trial). Cow 44 and 29 were therefore placed as equal bottom of the rank list.

3.2 Assessing Fearfulness

The number of times that each cow needed to negotiate each stimulus within 15s are shown in table 7.2

Fig. 7.1 Cow dominance rankings (highest first)



Central shaded rectangle shows the relative rankings,
the curved arrows show the deviations from that for each trial

Figure 7.2a: Cow 1107 (left) feeding while 81 (right) watches

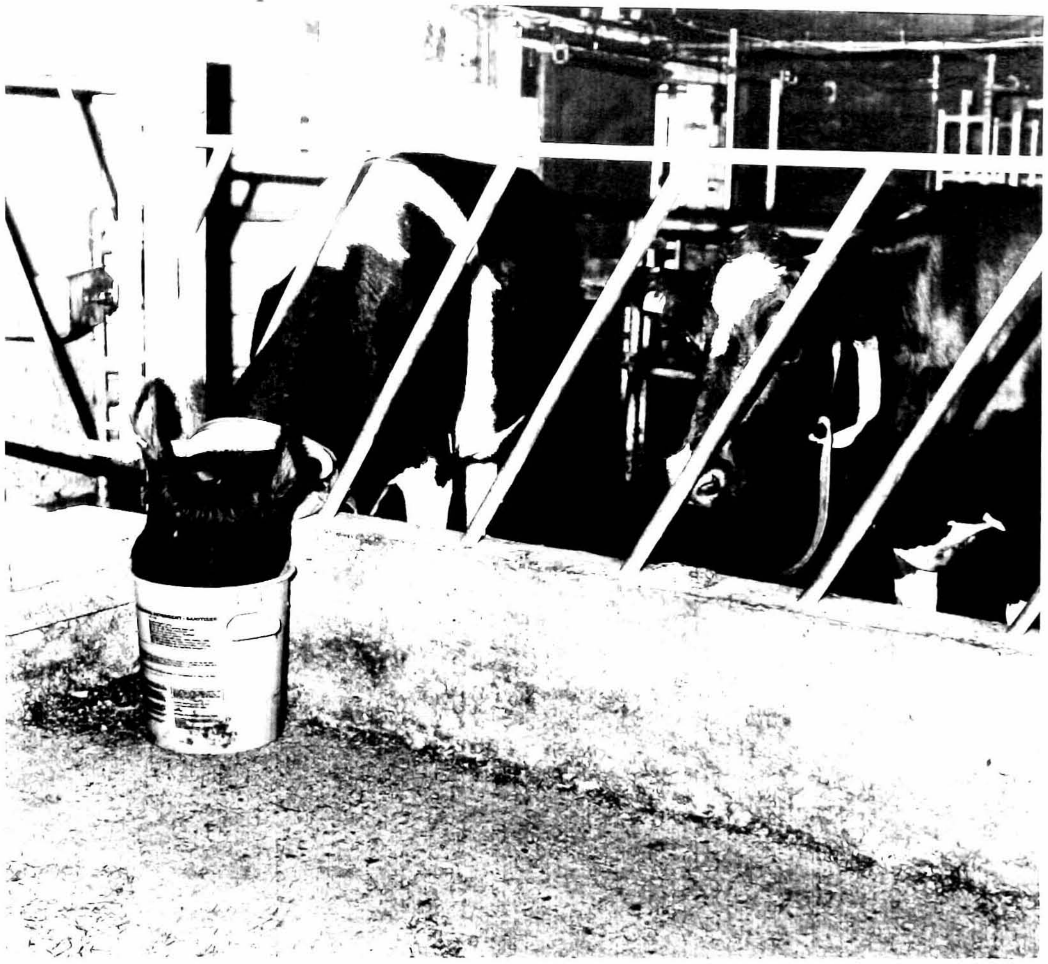


Figure 7.2b: Cow 81 challenges 1107 with a head butt to her flank

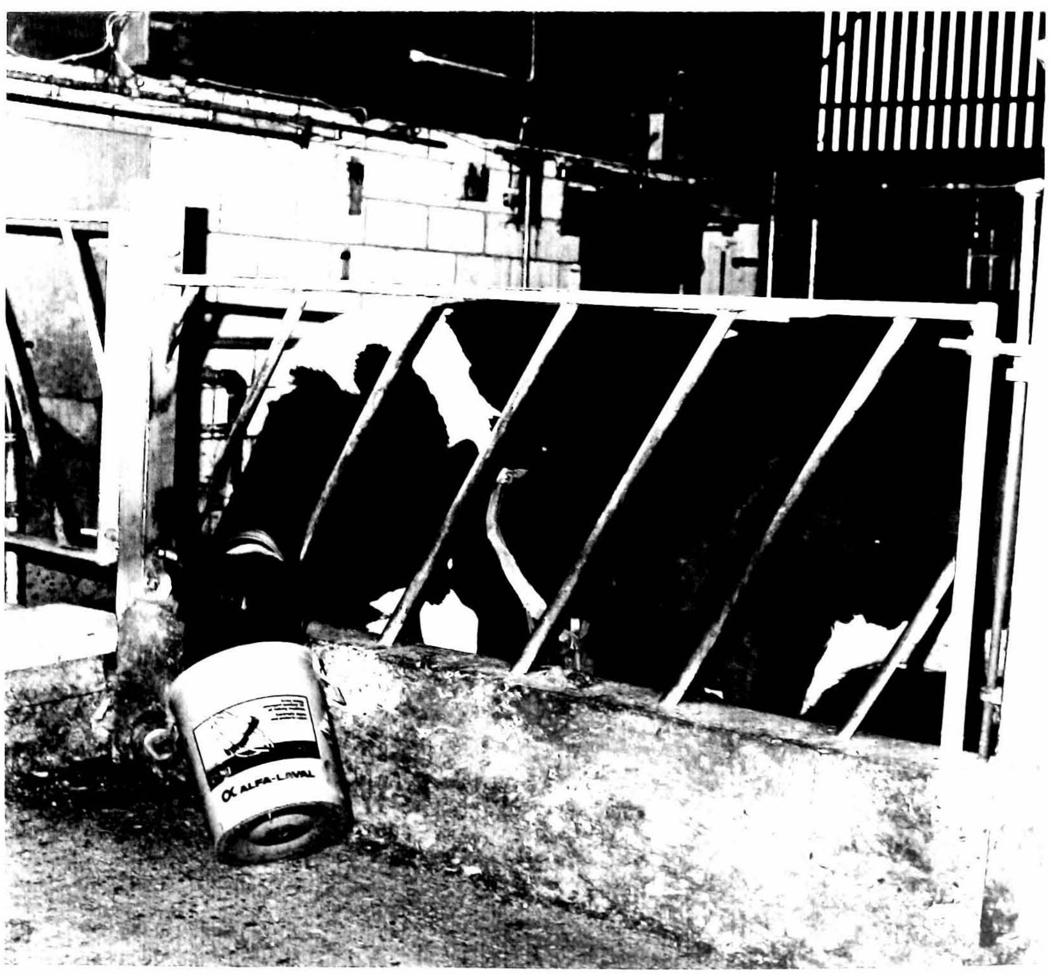


Table 7.2 Number of trials needed before the cows elected to pass three novel stimuli within 15s

Cow	Balloon	Rag	Music	Total	Fearful/Bold
29	2	2	4	8	Fearful
44	1	1	1	3	Bold
81	2	1	1	4	
123	3	2	1	6	Fearful
335	1	3	2	6	Fearful
533	1	1	1	3	Bold
815	1	4	1	6	Fearful
1035	1	1	1	3	Bold
1067	2	1	1	4	
1107	2	1	1	4	
1118	2	3	1	6	Fearful
1376	2	1	1	4	
2006	2	1	1	4	
2050	1	1	1	3	Bold

The five cows who were most fearful were 29, 335, 1118, 123 and 815. This group was called the 'fearful' group. The four cows who were least fearful were 1035, 533, 2050 and 44. This group was called the 'bold' group. The 'levels' quality of this data set renders it unsuitable to be used as a variate. No one treatment was significantly more aversive than another (Wilcoxon matched pairs test, two-way, $p>5\%$)

<u>3.3 Interactions between measures</u>

There appeared to be little interaction between fearfulness and rank or parity as shown in table 7.3.

Table 7.3 Rank and parity for each cow in the fearful and bold groups

Cow	Rank	Parity
29 (fearful)	13=	3
123 (fearful)	8	3
335 (fearful)	12	9
815 (fearful)	4	6
1118 (fearful)	9	2
44 (bold)	13=	2
533 (bold)	5	4
1035 (bold)	3	2
2050 (bold)	7	1

There was no significant difference between the ranks or parities of the bold and fearful cows ($p > 5\%$, Mann-Whitney U test, two-way, $n_1=5$, $n_2=4$). A graph showing the relationship between fearfulness score vs. age is shown in figure 7.3a. Figure 7.3b plots the relationship between age and rank. Figure 7.3c plots the relationship between fearfulness and rank.

Figure 7.2c Cow 81 accesses the feed bucket and 1107 withdraws

Figure 7.3a: Graph showing fearfulness score vs. parity

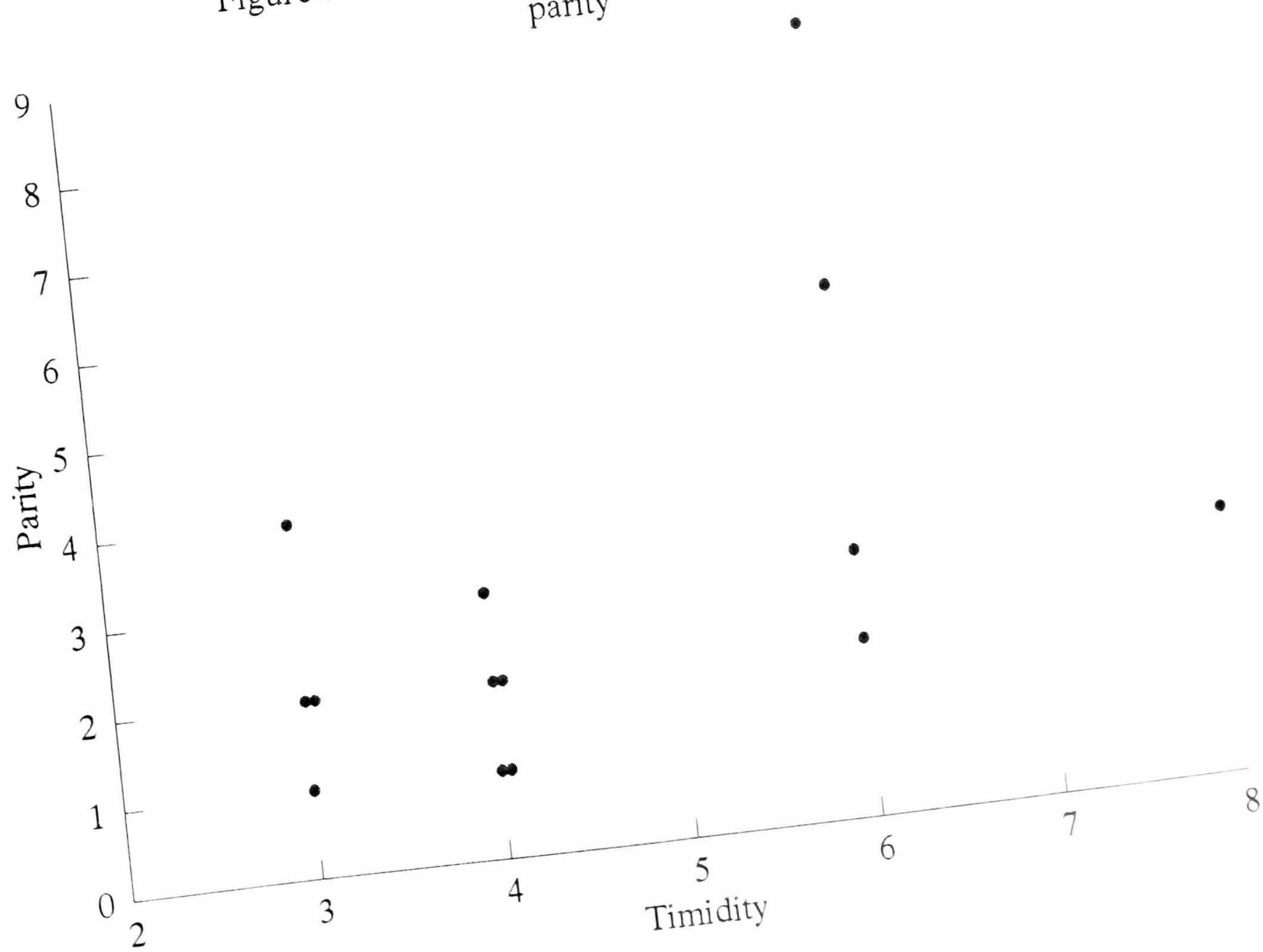


Figure 7.3b: Graph showing parity vs. dominance rank

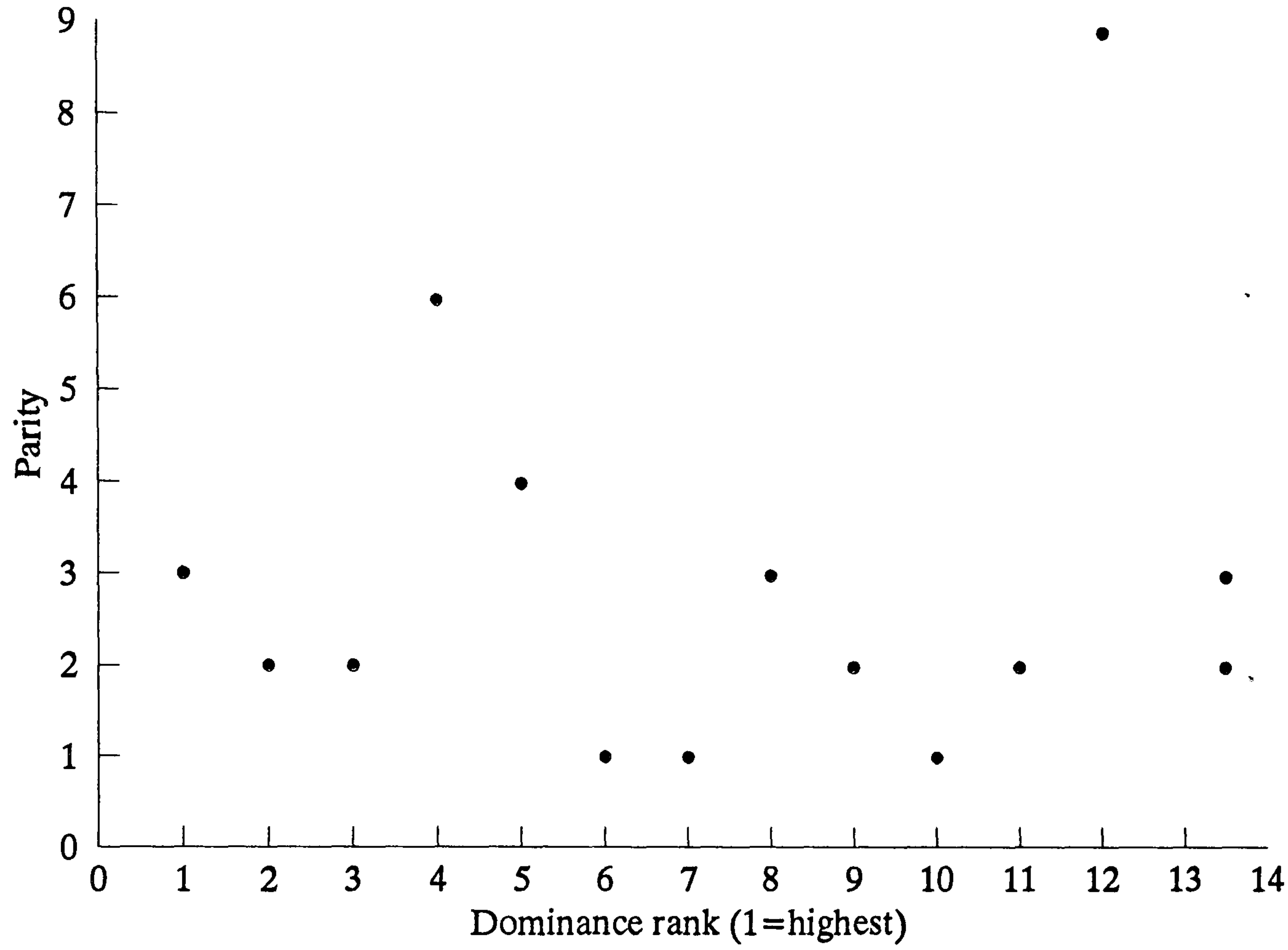
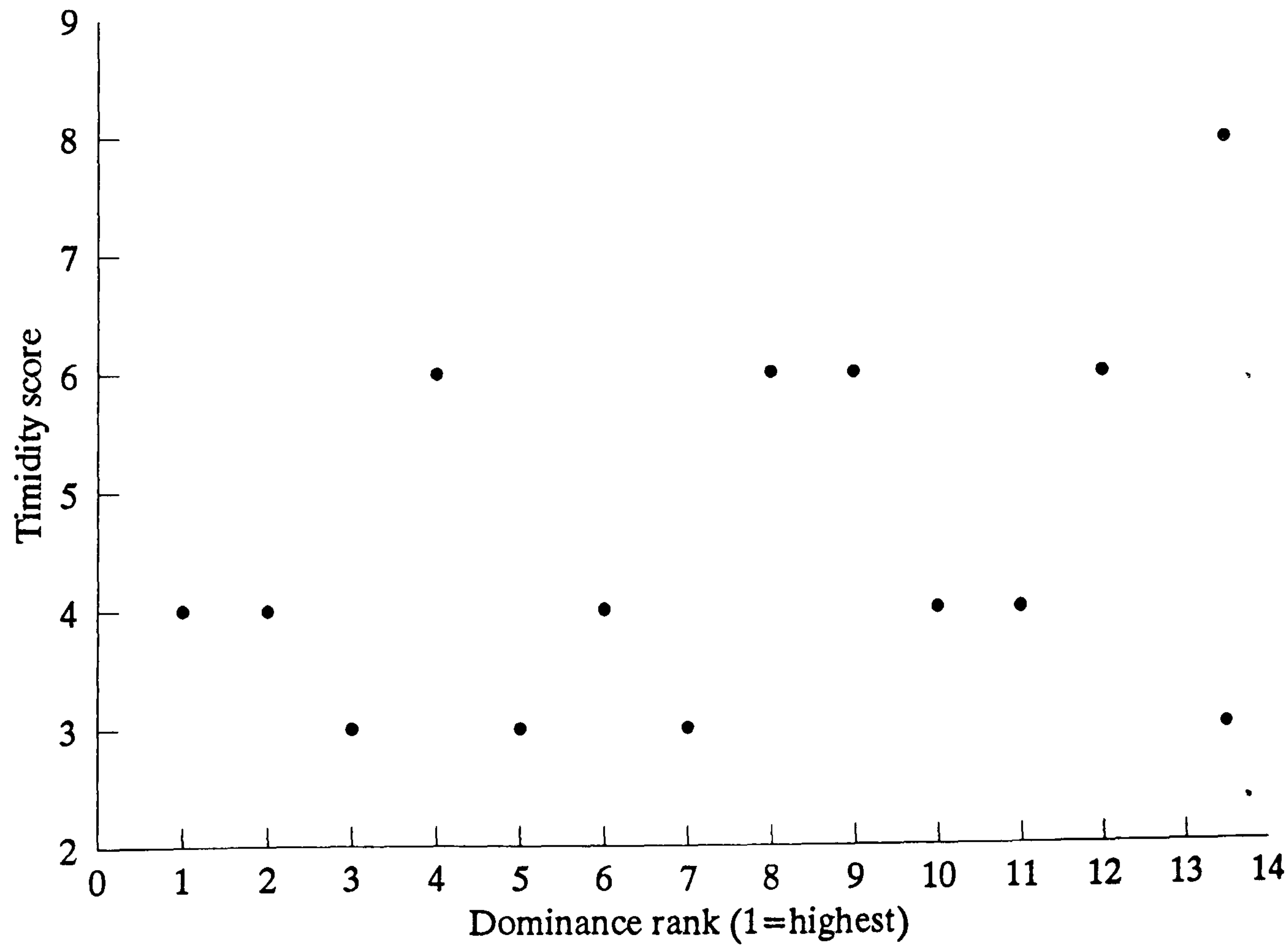


Figure 7.3c: Graph showing fearfulness score vs. dominance rank



4 Discussion

4.1 Assessment of rank

The method of rank assessment gave repeatable results within a short time; the duration of each test was little more than six hours. This is quicker than generating the data by non-invasive observation for the same number of cows. In addition, nearly all possible interactions were found; other methods of rank determination do not achieve this. Beilharz and Zeeb (1982) and Schein and Forman (1955) only found approximately 50%, and Beilharz and Myrea (1963) 65%, of all possible interactions. The observations in this experiment were also free of any value-laden judgements, i.e. a difference was only recorded if a cow succeeded in evicting another cow from the feed bucket. This was generally by a head butt to the cow's flank which met with no retaliation. Assessments based on non-invasive observations often use less clear indications of rank. No interactions resulted in the cows alternately accessing the bucket by head butting.

The level of aggressive behaviour generated by the provision of a highly motivating scarce feed source ensured that most of the animals actively tried to eat from it. Those animals who did not try very hard to eat (1035 and 29) may have been less motivated to feed than the other cows, although they also gave the impression of being generally unaggressive.

The few aberrant results reported (those triangular relationships that were unsubstantiated by the second assessment) might represent the nature of rank. The relationship between two cows may not be one of total dominance and total submission but a result of an `average', i.e. generally the dominant cow wins an interaction but occasionally the submissive cow may win an interaction. In this situation, it may have been that the low ranking cow was hungry and the motivation to eat was stronger than the fear of retribution from the higher ranking cow. These results suggest that it is probably advisable to conduct more than one rank test to be sure that any triangular relationships found are replicated and not merely created by opportunistic low ranking cows. The number of circular relationships found are similar to those reported elsewhere (Dickson et al. 1966, Beilharz and Mylrea 1963, Collis 1976, Miller and Wood-gush 1991, Schein and Fohrman 1955).

4.2 Assessment of fearfulness

The cows did not seem particularly affected by any one treatment. This may have been for a number of reasons; the cows may have been so highly motivated to feed that the novel object was insignificant. Alternatively the location of the test (in the AMS milking stall) may have interfered with their tolerance of novelty, meaning that the milking parlour was so rich in novelty that it was `predictably unpredictable'. The addition of a small amount of novelty may have had little effect.

Subjectively, the membership of each group did seem correct; those cows who were expected to perform badly did so and vice-versa. Allowing the cows a certain time to traverse the stall beyond which they were classed as fearful, would have helped to remove the confounding effects of curiosity since, presumably, curiosity would have only lasted for one test. On subsequent tests the cows may not have been curious about a stimulus that they had already investigated. This was, in part, evidenced by the large number of trials where the cows only needed one trial to negotiate the stimulus. This method would also have largely removed the problem of individual differences in the speed of walking possibly resulting from differences in motivation to feed and/or the state of the cows' hooves and legs. Using a similar design in an unfamiliar barren environment with stronger novel objects may have given a better distribution of results.

4.3 Interactions between age, rank and parity

There appeared to be little interaction between age, rank or parity; regressing age and fearfulness vs. rank showed there to be little interaction. The analysis of the bold and fearful group showed that both had similar average rank, and only slightly differing average parity. These results agree with those of Dickson et al. (1970) who also found no relationship between age, rank and a measure of fearfulness. Thus, for the purposes of the analyses in chapters 8,9 and 10, it seems safe to assume that rank, fearfulness and age, in this experiment, were independent.

5 Conclusions

The novel method for assessing rank gave repeatable results with only a few circular relationships. Although this method did not quantify the difference in dominance, it was quicker and most interactions were recorded, which may not be the case in conventional assessments. The method for assessing fearfulness produced data of `levels' quality, however it was possible to group those cows who were most fearful and most bold. There appeared to be little interaction between rank and bold or fearful cows and neither appeared significantly affected by age.

CHAPTER 8

EFFECT OF FOOD TYPE AND LOCATION, RANK, FEARFULNESS AND AGE ON THE ATTENDANCE OF DAIRY COWS AT AN AUTOMATIC MILKING SYSTEM

1 Introduction

The practical application of voluntary automatic milking, where cows are milked when they choose, depends on the behaviour they exhibit. Principal among these behaviours is attendance. In peak lactation cows should be milked by the system three or more times per day. This will allow a 10-15% milk yield gain associated with increased milking frequency (e.g. Hillerton and Winter 1992, Wilde and Peaker 1990, Knight and Wilde 1993).

Attendance at the system can be 'operator' or 'cow' controlled (referred to as 'active' and 'passive' selection respectively by Ketelaar-de-Lauwere 1992 and Winter 1993). When the system is operator controlled, the cow has to enter the system to eat food. The AMS is positioned between the bedded area and the feeding area. Once in the system the cow is either selected for milking, if the interval since the last milking is long enough, or else diverted directly into the feeding area (details of the system and routing can be found in chapter 2). The cow has no control over which of these options occurs. When attendance is under `cow' control the feeding area is directly accessible from the bedded area.

Ketelaar-de-Lauwere (1992) showed that cow control could only ensure adequate attendance if preceded by a period of operator controlled selection. The effect of long-term cow control may result in a reducing number of visits if the cows learn that they do not have to enter the AMS to eat. Ketelaar-de-Lauwere (1992) also showed that under operator control the cows ate forage less often and for less time in total. Similarly Winter (1993) showed fewer forage eating bouts of longer duration under operator as opposed to cow control. In neither experiment was the amount of forage consumed measured. AM systems that use forage to attract cows into the AMS may be placing an obstruction between the cow and forage in the form of unpredictable (the cow may not know whether she will be milked or diverted) one-way races. A system which modifies forage feeding behaviour may be undesirable on economic grounds if it alters food conversion efficiency, reduces milk yield or predisposes the cows to metabolic disease as a result of temporarily modified or reduced forage intake. Altered forage feeding behaviour may reduce welfare if it increases the incidence of metabolic disease or constrains the level of choice (i.e. when to eat forage and for how long) in the cow's environment.

Rossing et al. (1985) showed that adequate attendance was generated by a simulated automatic milking stall located in a concentrate feeder (with the teat cups being manually attached but with voluntary attendance). This method of attraction may be an alternative to using forage to lure cows into the system. If so, then this may provide a method of gaining the benefits of operator control without the potential risks to welfare and economic performance generated by modified forage feeding behaviour.

Winter (1993) showed that when cows were fed forage in the exit area of an AMS, there were marked peaks and troughs of attendance through the day; some of these peaks may have been in response to the provision of fresh forage. Peaks and troughs of attendance may be wasteful of the system's time and may cause the cows to queue to enter at particular times of the day. Some cows may 'give-up' before entering the system, especially low ranking or fearful cows.

There may be factors modifying how often individual cows visit the system. Old cows may visit the system less often than young cows because they move around their housing less than young cows (Kempkens and Boxberger 1987). Fearful cows may visit the system less often, and enter later, than bold cows if there are some aversive aspect to the AMS. Low ranking cows may visit the system less often and later if there is competition to enter from higher ranking cows.

Feeding concentrate in the parlour creates dust, encourages vermin and may encourage misbehaviour. It may, however, encourage the cows to use the system and may increase yield, milk flow rate and reduce milking time via its action on oxytocin (Svennersten and Samuelsson 1999, Svennersten et al. 1990).

This experiment was designed to assess the effects of feeding either forage or concentrate in the exit area and feeding concentrate in the parlour on attendance. The effect of age, fearfulness and rank on attendance was also considered. The effect of the treatments on the order of attendance were also studied.

This chapter was the first in a series of three looking at the effect of feed type and location on attendance at, and behaviour in, the automatic milking system.

2 Materials and Methods

2.1 The System

The design of the system has been described in detail in chapter 2.

2.2 General Method

The general operation of the system was the same as that described in chapter 2.

Between 06:00 and 21:00, any cow volunteering to enter the AMS was milked if the interval since her last visit was greater than four hours and diverted if not. Potentially, a cow could be milked up to four times per day if she attended at four hour intervals. Between 21:00 and 06:00 the system was shut down but with the ID stall gates were left open, and the diversion gate set, so the cows could walk directly from the bedded area into the exit area to feed.

The forage was the same as that described in chapter 2 and could either be fed in the exit area or direct from the bedded area, behind a feed barrier of equal length (5m) in each. The forage was delivered once per day between 06:00 and 07:00, the uneaten forage was forked to the barrier at 13:00 and again at 21:00.

The concentrate (BOCM/Pauls 1592 Dairy Nuts, see appendix 4) was rationed via two automatic feeders (ALPRO, Alfa-Laval Ltd, Cwmbran, Gwent). Each cow received four kg per day which was dispensed when the cow triggered either feeder from the transponder around her neck. The concentrate was delivered on a variable schedule whereby the cow received as much concentrate as had accrued since her last visit, as a proportion of her 24hr ration. If the cow returned to the feeders within 30 minutes of her last feed however, she was not rewarded. The feeders were positioned such that moving a barrier allowed access from either the exit area only or the bedded area only. The concentrate feeders were filled once per day at 13:30.

The system, parlour and yard were cleaned twice per day at 13:30 and 21:00. The cleaning took approximately 30 minutes, during which time the system was not available to the cows.

Any cow who had not voluntarily attended the system during the day was manually collected from the bedded area and milked 'non-voluntarily' at 21:00.

2.3 The experimental design and data recording

The experiment was divided into two parts. The first studied the effect of feeding forage or concentrate in the exit area of the milking stall. The second studied the effect of feeding or not feeding concentrate in the milking stall. Both parts of the experiment were combined in one experimental design.

The first part of the experiment was divided into three eight-day periods. During the first period (forage1) the cows were fed forage in the exit area of the milking stall. Concentrate was provided via the automatic concentrate feeders which were directly accessible from the bedded area. During the second period of the experiment (conc2) the cows were allowed direct access to the forage from the bedded area but the automatic concentrate feeders were now only accessible through the AMS. The third period of the experiment (forage3) reverted to the same design as the first period. The locations of the forage and concentrate during this experiment are shown diagrammatically in figures 8.1a and b. Figure 8.2a shows a cow eating forage in the exit area, and figure 8.2b shows a cow feeding from one of the concentrate feeders.

Within the treatments in the first part of the experiment the cows were also divided into two groups of seven. The treatment here was being fed or not fed 1kg of concentrate in the parlour, with each group being fed or not fed alternately in each period. This formed the second part of the experiment.

The experimental design showing the treatments in part one and two is shown in table 8.1.

Table 8.1 Details of experimental design

	Period 1	Period 2	Period 3
Exit area food type	Forage	Concentrate	Forage
Bedded area food type	Concentrate	Forage	Concentrate
Name code	*`Forage1'*	*`Conc2'*	*`Forage3'*
Parlour feed- Group 1	Fed	Not fed	Fed
Group 2	Not fed	Fed	Not fed

The following data were recorded automatically by the computer management systems; the cow's identity, time, date and whether she was diverted or accepted for

Figure 8.1a: Location of silage and concentrate feeders in periods 1 and 3

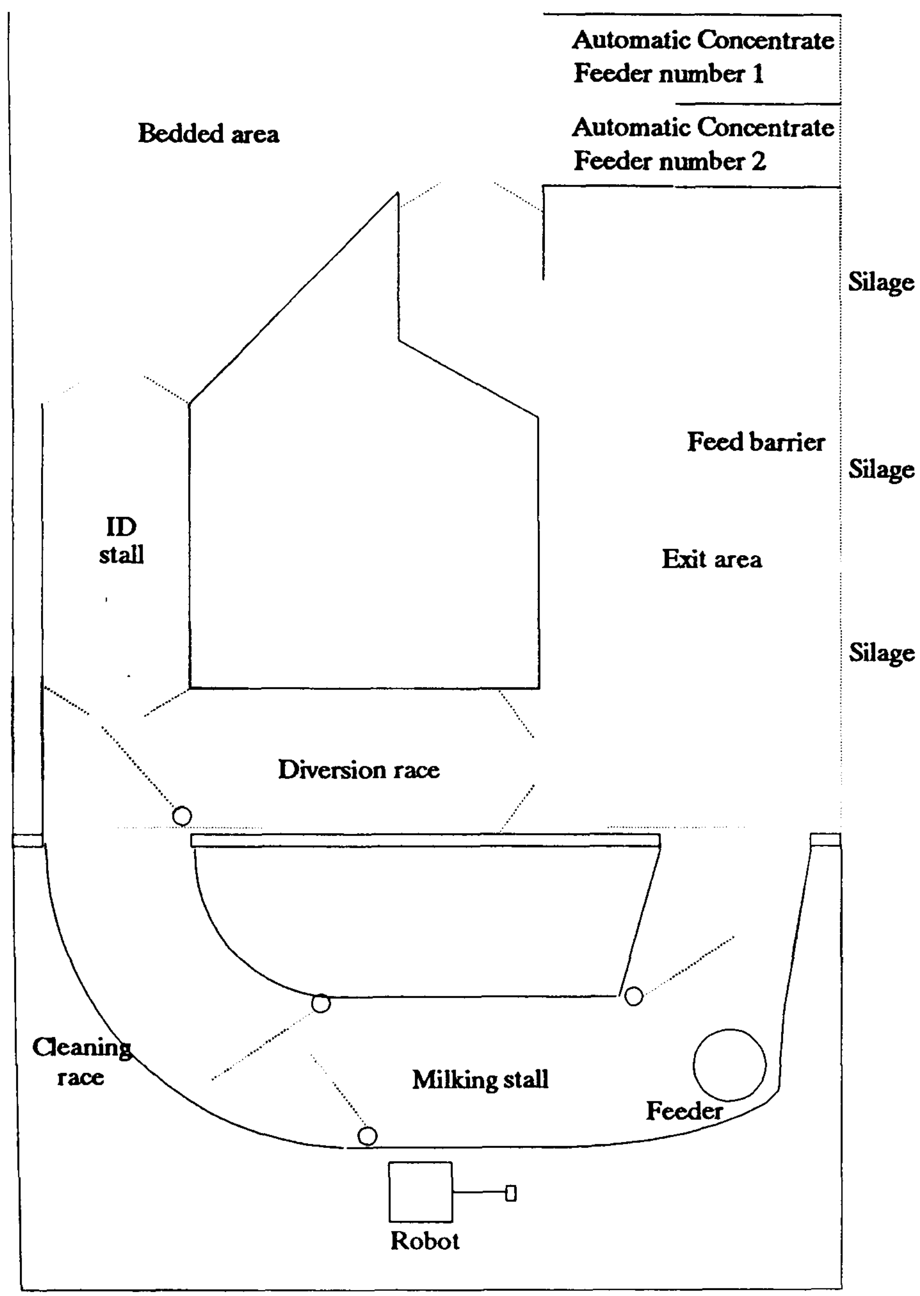


Figure 8.1b: Location of silage and concentrate feeders in period 2

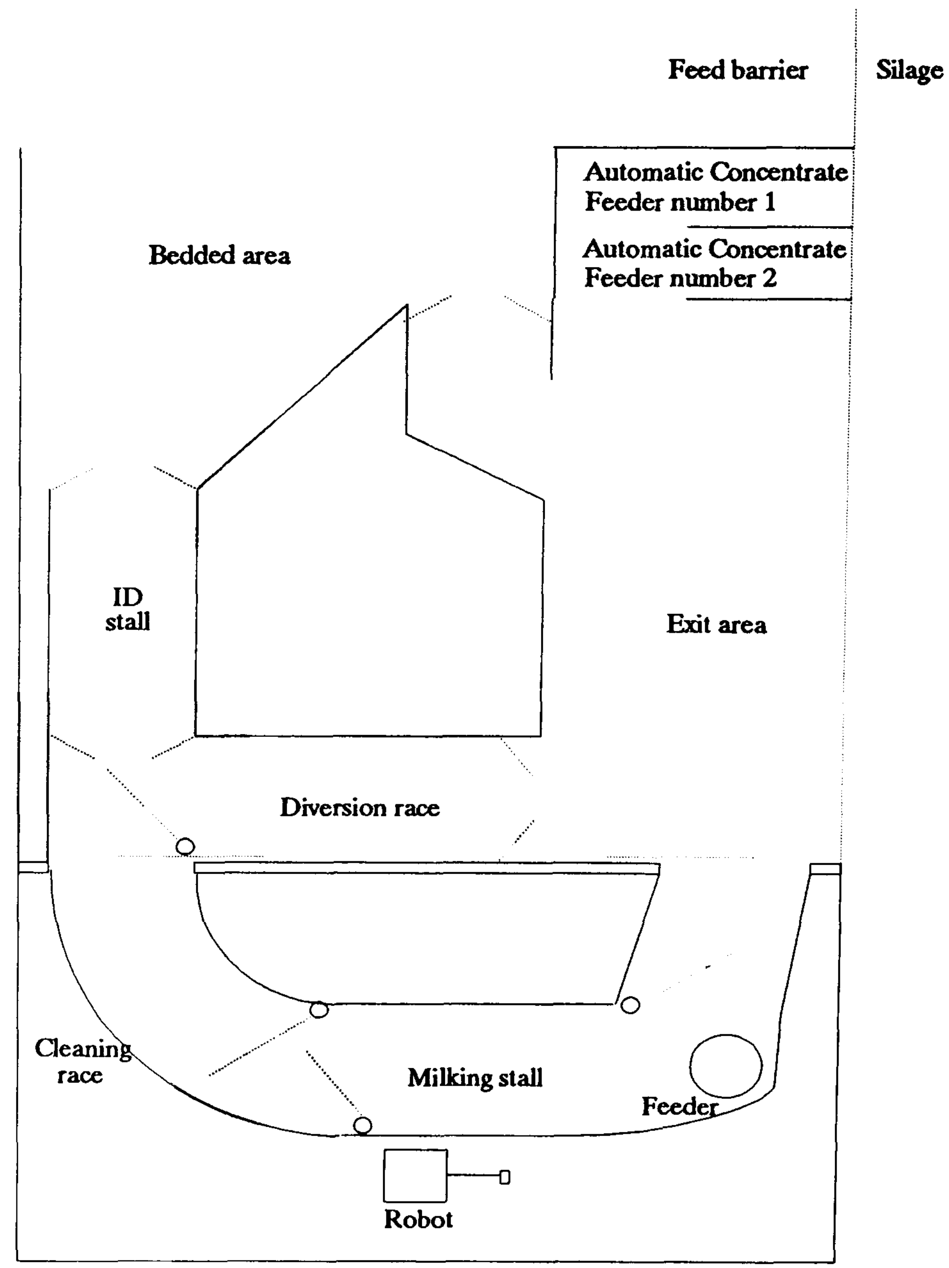


Figure 8.2a: Cow 335 eating forage in the exit area

Figure 8.2b: Cow 335 eating concentrate in the exit area

milking. Other data were recorded by cameras attached to a video recorder. These data provided a continuous record of the cows' movements throughout the last three days of each of the three treatment periods.

2.4 The animals

Fourteen cows were selected from the herd at Cheseridge Farm, belonging to the Institute for Animal Health, Compton. These were animals who were thought to have appropriate udder conformation for accurate automatic teat-cup attachment. Details of these animals are given below in tables 8.2 and 8.3 (where DIM indicates days in milk).

Table 8.2 Cow Data

Cow	Group	Rank[a]	Fearfulness[a]	Age[b]	Yield (l)	Parity	DIM
29	1	13=	Fearful	-	23.5	3	188
44	2	13=	Bold	-	20.1	2	207
81	1	1	-	-	24.4	3	126
123	2	8	Fearful	-	23.8	3	132
335	1	12	Fearful	Old	21.9	9	171
533	2	5	Bold	Old	26.0	4	126
815	1	4	Fearful	Old	25.1	6	132
1035	2	3	Bold	-	23.3	2	137
1067	1	11	-	-	20.2	2	127
1107	2	2	-	-	24.5	2	131
1118	1	9	Fearful	-	22.2	2	172
1376	2	6	-	Young	21.2	1	186
2006	1	10	-	Young	24.2	1	173
2050	2	7	Bold	Young	20.0	1	190

[a] For derivation and definition see chapter 7
[b] Cows grouped into three oldest and youngest (by parity)

Table 8.3 Average yields, parities and days in milk (DIM) for each group

	Mean Yield (l) (s.d.)	Mean Parity	DIM (s.d.)
Group 1	23.07 (1.72)	3.71	155.57 (26.17)
Group 2	22.70 (2.31)	2.14	158.43 (34.35)

2.5 Training

The training period started 10 days before the start of the experiment. For the first three days the cows were run through the system, without being milked, to accustom them to the AMS. The cows were milked in the farm's main parlour but housed together in the bedded area of the AMS. For the next five days the cows were milked at fixed times twice per day (starting at 07:00 and 16:00) in the system. During this time the teat coordinates were programed into the management database and the cows accustomed to the milking process. The final two days of the training period involved allowing the cows free access to the system and milking stall between 07:00 and 19:00. During the training period the cows were fed concentrate and forage in the exit area but nothing was fed in the parlour.

2.6 Analysis

The attendance rates for the effects of the two treatments were determined by analysis of variance. The data from the three days in each period were summed to generate a data set which was normally distributed. For this analysis the data were blocked and nested; cows were nested within groups, which were nested within periods. The main and interactive effects of the treatments were analysed.

The effect of rank on attendance and order of attendance was assessed using the Spearman's rank statistic and the effects of fearfulness and age on attendance and order of attendance using the Mann-Whitney U test. The uniformity of the order of attendance for each of the three periods was analysed using Kendall's coefficient of concordance for each of the three periods for each of the three days within each period. The uniformity of the pattern of attendance with time was analysed using the Chi-square coefficient (with the expected frequency being the average attendance rate for each hour during the experimental day).

The time budgets for lying and feeding were determined from the continuous video recording for eight cows for the least disturbed day (by farm staff etc.) in each of the three recording periods. The total time, number of bouts and bout duration for forage feeding and lying were determined for each of the focal 24hrs. A cow was recorded as feeding if her head was through the feed barrier. A new feeding bout had to be preceded by a non-feeding period of at least five minutes, the same was also true for lying bouts. The effect of the location of forage on forage feeding and lying behaviour was examined by analysis of variance for the timings, and the Wilcoxon matched pairs test for the number of bouts, of these behaviours.

3 Results

3.1 Factors affecting attendance rate

The summary table, 8.4, shows the mean attendance rates for the various treatments.

Table 8.4 Summary of factors affecting attendance to the AMS/cow/day

Treatment in exit area*:	Forage	Concentrate
Mean number of attendances	6.0	4.1
Mean number of milkings	2.6	2.4
Treatment in parlour*:	Fed	Not Fed
Mean number of attendances	5.6	5.1
Mean number of milkings	2.6	2.4
Fearfulness:	Fearful	Bold
Mean number of attendances	2.3	2.6
Mean number of milkings	3.9	6.3
Age:	Young	Old
Mean number of attendances	8.33	4.33
Mean number of milkings	3.07	2.30

*data taken from main effects of analysis of variance

3.1.1 Effect of exit area and parlour feeding feed on attendance

The effects of the feed type in the exit area and feeding or not feeding in the parlour were analysed using analysis of variance. The data were blocked (nested) by period, group and individual animals. The treatment structure was forage/concentrate in the exit area and fed/not fed in the milking stall, with the analyses of variance being carried out on the total number of visits, diversions and milkings. More details of the analysis can be found in appendix 8a.

The effects of the treatments on the total number of visits are shown in table 8.5.

Table 8.5 Effect of treatments on the total number of attendances per cow over the last three days of each period, showing main and interactive effects

Main effects	Number of visits	s.e.d	Sig
Forage in exit area	17.9	0.25	2.8%
Concentrate in exit area	12.3		
Fed in parlour	16.8	0.70	27.4%
Not fed in parlour	15.3		
Interactions	**Fed in parlour**	**Not fed in parlour**	**Sig**
Forage in exit area	$16.3^{a,c}$	$19.6^{a,d}$	6.5%
Concentrate in exit area	$17.9^{b,c}$	$6.7^{b,d}$	

(superscript letters following interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a} =0.86, ^{b} =1.21, ^{c} =0.78, ^{d}=0.78)

When the cows were fed concentrate in the exit area, they visited the system less frequently than when they were fed forage. There was no effect of feeding in the parlour on attendance. The interactive effect approached significance; when the cows were 'fed concentrate in the exit area and not fed in the parlour' they appeared to visit the system less than in the other treatments.

The effect of the treatments on the number of milkings are shown in table 8.6.

Table 8.6 Effect of treatments on the total number of milkings per cow over the last three days of each period, showing main and interactive effects

Main effects	Number of milkings	s.e.d	Sig
Forage in exit area	7.82	0.06	5.2%
Concentrate in exit area	7.07		
Fed in parlour	7.9	0.18	16.3%
Not fed in parlour	7.24		
Interactions	**Fed in parlour**	**Not fed in parlour**	**Sig**
Forage in exit area	$7.43^{a,c}$	$8.21^{a,d}$	5.4%
Concentrate in exit area	$8.86^{b,c}$	$5.29^{b,d}$	

(superscripts in interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a} =0.21, ^{b} =0.30, ^{c} =0.20, ^{d}=0.20)

There was an effect of feeding forage or concentrate in the exit area on attendance which approached significance. This difference was small, when the cows were fed concentrate in the exit area it resulted in 0.25 fewer milkings/cow/day than when they were fed forage in the exit area. There was no main effect on the number of milkings of feeding or not feeding in the parlour. There were however, interactions between the type of food in the exit area and feeding or not feeding in the parlour which approached significance. When the cows were 'fed concentrate in the exit area and not fed in the parlour' they were milked less often than when they were 'fed in the parlour and fed concentrate in the exit area'.

Table 8.7 shows the effect of the treatments on the number of diversions.

Table 8.7 Effect of treatments on the total number of diversions per cow over the last three days of each period, showing main and interactive effects

Main effects	Number of diversions	s.e.d	Sig
Forage in exit area	10.11	0.19	2.4%
Concentrate in exit area	5.21		
Fed in parlour	8.90	1.77	35.0%
Not fed in parlour	8.05		
Interactions	**Fed in parlour**	**Not fed in parlour**	**Sig**
Forage in exit area	$8.86^{a,c}$	$11.36^{a,d}$	7.0%
Concentrate in exit area	$9.00^{b,c}$	$1.43^{b,d}$	

(superscripts in interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a} =0.64, ^{b} =0.91, ^{c} =0.59, ^{d}=0.59)

The effect of the feed type in the exit area had a significant main effect on the number of diversions. When the cows were fed concentrate in the exit area they were diverted 1.6 times/cow/day less than when they were fed forage in the exit area. There was no effect of feeding or not feeding concentrate in the parlour on attendance. The interaction between the treatments approached significance. Not feeding in the parlour and feeding concentrate in the exit area led to fewer diversions than not feeding in the parlour and feeding forage in the exit area.

Table 8.8 shows the ratio of milking to diverting for each of the three periods.

Table 8.8 Total number of milkings and diversions for the last three days of each period showing the ratio of milking to diverting

	Forage1	Conc2	Forage3
Total no. Milkings/d	36	31.6	36.4
Total no. Diversions/d	49.7	28.3	46
Ratio	0.72	1.12	0.79

There were fewer diversions when concentrate was fed in the exit area. This increased the ratio of milking to diverting, i.e. when concentrate was fed in the exit area, the AMS spent a greater proportion of its operating time milking, than when forage was fed in the exit area.

3.1.2 Effect of rank on attendance

The effects of rank on aspects of attendance are shown in figures 8.3a and b and in table 8.9. For each category this is the total number of visits for the nine recording days of the three periods. In the rank analyses the lowest ranking cow was ranked no.14, whereas the highest ranking cow was ranked no.1.

Table 8.9 Correlation between rank and three aspects of attendance for each cow over the nine recording days of the three periods. Showing the Spearman's rank correlation coefficient (n=14)

	Spearman's rank correlation coefficient	Significance
Total attendances	-0.48	<5%
Total diversions	-0.53	<5%
Total milkings	-0.27	n.s.

While the total number of diversions and attendances was significantly correlated with rank (lower ranking cows had fewer attendances and diversions), the actual number of milkings was not significantly correlated. These data are plotted in fig 8.3a

In more detail, the effect of each period on the correlation between rank and total attendance is shown in table 8.10.

Table 8.10 Correlation between rank vs. total attendance (summed over the last three days of each period). Showing the Spearman's rank correlation coefficient (n=14)

	Spearman's rank correlation coefficient	Significance
Forage1 vs. rank	-0.50	<5%
Conc2 vs. rank	-0.48	<5%
Forage3 vs. rank	-0.51	<5%

In all three periods there was a significant correlation between rank and attendance ($p<5\%$, Spearman's rank test, n=14). These effects are plotted in figure 8.3b.

3.1.3 Effect of fearfulness on attendance

The analysis for this section is based on the Mann-Whitney U test using the four cows in the bold group and five in the fearful group. The data for the various parameters are shown in the table 8.11.

Table 8.11 Effect of fearfulness on aspects of attendance averaged over the nine recording days of the three periods. Significance derived from the Mann-Whitney U test

	Fearful	Bold	Significance
Milkings/cow/day	2.3	2.6	n.s.
Diversions/cow/day	1.6	3.7	n.s.
Total Visits/cow/day	3.9	6.3	n.s.

Fearful cows did not visit the system less often than the bold cows ($p>5\%$, Mann-Whitney U test, one-way, $n_1=4$, $n_2=5$), although there was a large numerical difference between the number of diversions (and therefore visits) for the bold and the fearful cows.

3.1.4 Effect of age on attendance

The effect of age on the visit categories is shown in table 8.12. The analysis is similar to the fearfulness analysis.

Figure 8.3a: Effect of rank on total number of visits, milkings and diversions

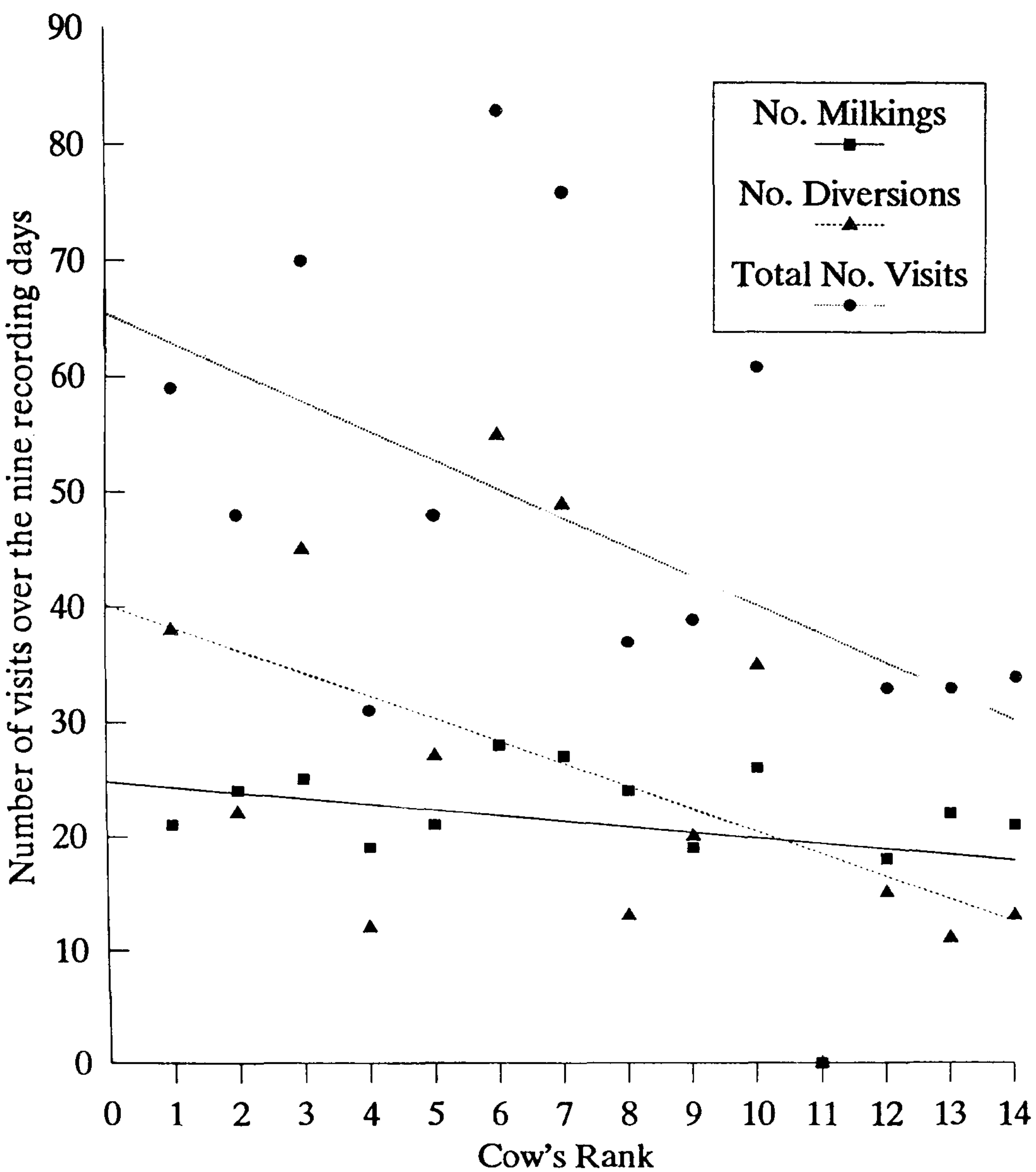


Figure 8.3b: Effect of food type on rank vs. total number of visits for each period

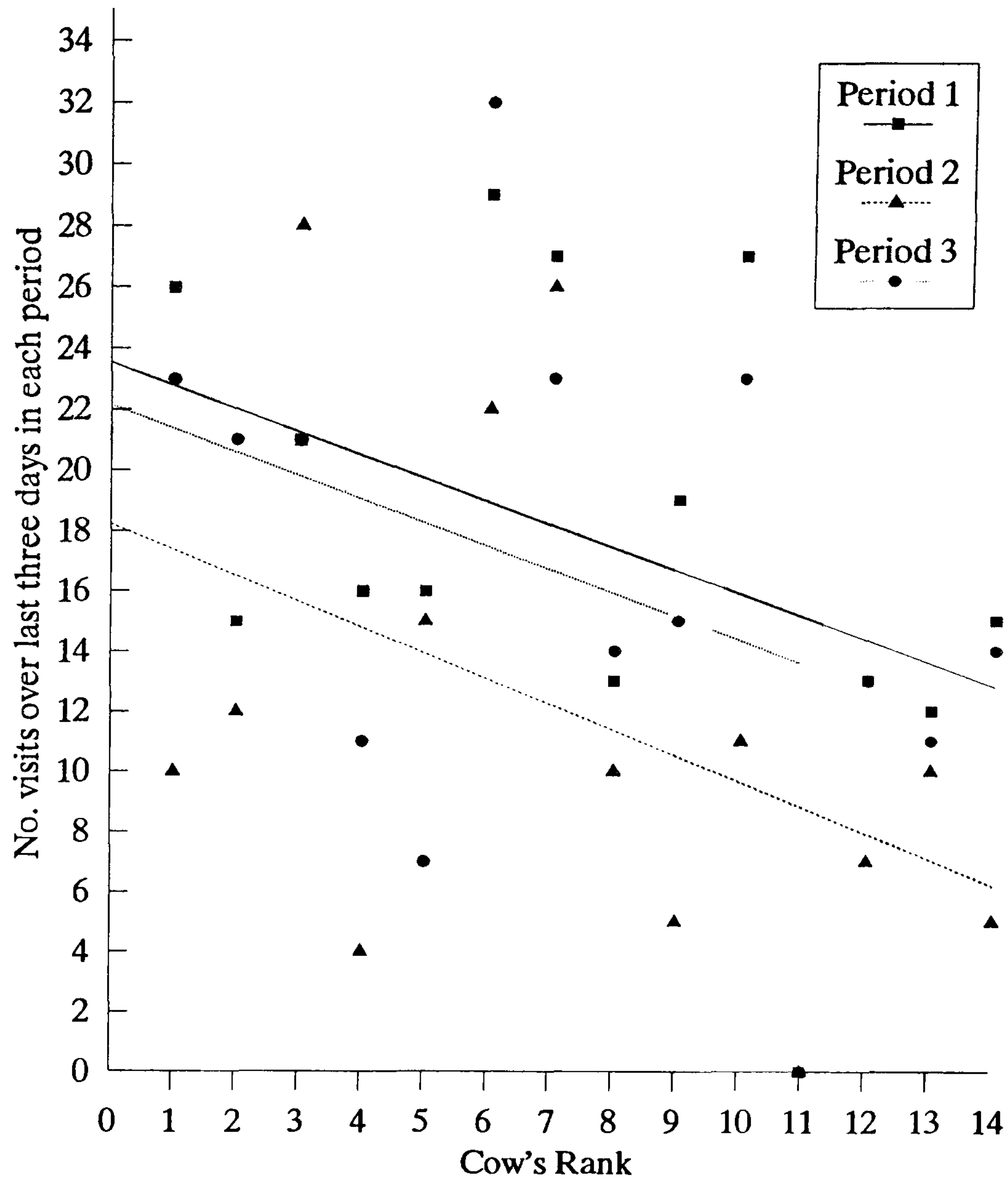


Table 8.12 Effect of age on aspects of attendance summed over the nine recording days of the three periods. Significance derived from the Mann-Whitney U test

	Old	Young	Significance
Milkings/cow/day	2.3	3.1	n.s.
Diversions/cow/day	2.0	5.3	$p<5\%$
Total visits/cow/day	4.3	8.3	$p<5\%$

Young cows visited the system, and were consequently diverted more, than old cows ($p<5\%$ Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$). There was no significant difference in the number of milkings ($p>5\%$, Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$).

3.2 Order of attendance

The order of attendance was based on the rank order in which the cows first visited the AMS each day; return visits were ignored.

3.2.1 Effect of exit area feed on the order of attendance

This analysis was performed using Kendall's Coefficient of Concordance using the rank orders derived from the last three days of each period. The three attendance rank orders, within each period, were then compared with each other. The results of this analysis are given in table 8.13.

Table 8.13 Orderliness of cow entry in each of the three periods

	Forage1	Conc2	Forage3
Kendall's Coefficient (n=14)	0.479	0.662	0.537
Significance	13.3%	<5%	<10%

The only significant order of attendance was seen when the cows were fed concentrate in the exit area. In period three, when the cows were fed forage in the exit area, they appeared to have some order of attendance but this was not significant ($p<10\%$). In the first period, under the same treatment, there was no discernible order ($p>5\%$).

3.2.2 Effect of feeding in the parlour on order of attendance

The effect of feeding in the parlour on the order of attendance is shown in table 8.14. The data were derived from the average attendance rank for each cow in group 1 and 2 (fed or not fed) over the last three days of each period. The data were analysed using the Wilcoxon matched pairs test for both replicates (group 1 and 2) and also for each pseudo replicate within each group (comparisons between periods 1 and 2, and periods 2 and 3).

Table 8 .14 Effect of feeding or not feeding in the parlour on average attendance rank for each group in each period. Significance derived from the Wilcoxon matched pairs test (n=7).

		Fed	Not fed	Significance
Group 1	Periods 1 and 2	7.1	10.3	$p<5\%$
	Periods 2 and 3	4.8	8.1	$p<1\%$
Group 2	Periods 1 and 2	7.3	10.2	$p<1\%$
	Periods 2 and 3	4.2	6.7	$p<1\%$

Feeding cows in the parlour encouraged them to enter the parlour significantly earlier in the attendance order than when they were not fed (Wilcoxon Matched pairs test, one-way, $n_2=7$) in all replicates and pseudo replicates.

3.2.3 Effect of fearfulness, age and rank on the order of attendance

The effect of fearfulness on the order of attendance was assessed by using the average rank for each of the fearful and bold cows for each period, and the Mann-Whitney U test. The average attendance rank of the fearful cows over the three periods was 7.8, while for the bold cows it was 5.4. This was not significant ($p>5\%$, Mann-Whitney U test, one-way, $n_1=4$, $n_2=5$).

The old cows had an average attendance rank of 7.5 while the young cows had an average attendance rank of 5.8. This difference was also not significant ($p>5\%$, Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$).

There was no significant relationship between the average attendance rank for any period and dominance rank ($p>5\%$, Spearman's rank, n=14).

3.3 Pattern of Attendance

The pattern of attendance was calculated using the Chi-square statistic. For each of the 15 hours during the day, the total number of observed (*O*) visits (total visits, milkings visits and diversion visits) were determined. The average number of visits for each hour was then calculated and used as the expected value (*E*) for each hour. Using the Chi-square analysis, the observed number of visits was compared with the expected number for each hour using the equation $(O\text{-}E^2)/E$. The Chi-square coefficients, derived from the equation, for each hour could then be used as a measure of the uniformity of distribution through the day. Large differences between the average expected (*E*) number of visits and the observed (*O*) number of visits result in large coefficients. The results of this analysis are shown in table 8.15.

Table 8.15 Distribution of attendance during the day for each period, with significant results showing deviations from the average attendance rate (Chi-square test d.f. =14)

	Milkings			Diversions			Total		
	Sil1	Conc2	Sil3	Sil1	Conc2	Sil3	Sil1	Conc2	Sil3
Sig.	<1%	n.s.	<1%	<1%	n.s.	<1%	<1%	n.s.	<1%

The type of diet in the exit area of the milking stall affected the distribution of attendance. When concentrate was fed in the exit area the cows tended to visit the system evenly throughout the day. When forage was fed in the exit area the pattern of attendance differed significantly from the average attendance rate ($p < 1\%$, Chi-square test, $n=15$).

The cycle of attendance is represented in figures 8.4a and b. These graphs plot the value of the Chi-square coefficient for each hour during the day, the larger the coefficient, the less the agreement between the observed and expected values. Figure 8.4a, which shows the Chi-square coefficients for total attendance, clearly exhibits the peaks and troughs of attendance in periods 1 and 3. The peaks occurred between 06:00 and 07:00, 09:00 and 11:00, and 13:00 and 16:00. These peaks are also shown in graph 8.4b which shows the Chi-square coefficient for the number of milkings.

Figure 8.4a: Magnitude of difference between observed and expected frequency of attendance during the day, using the Chi-square coefficient

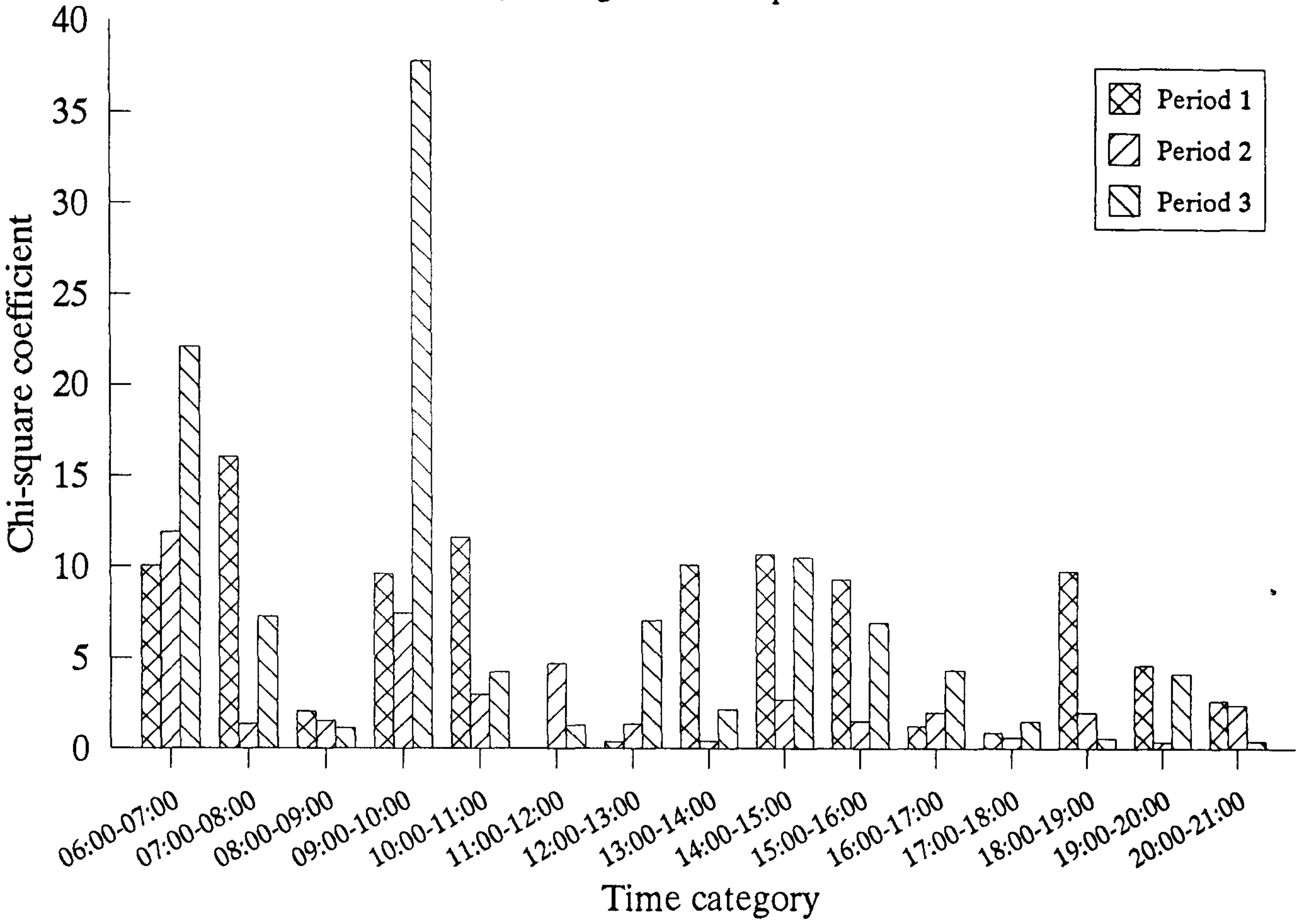
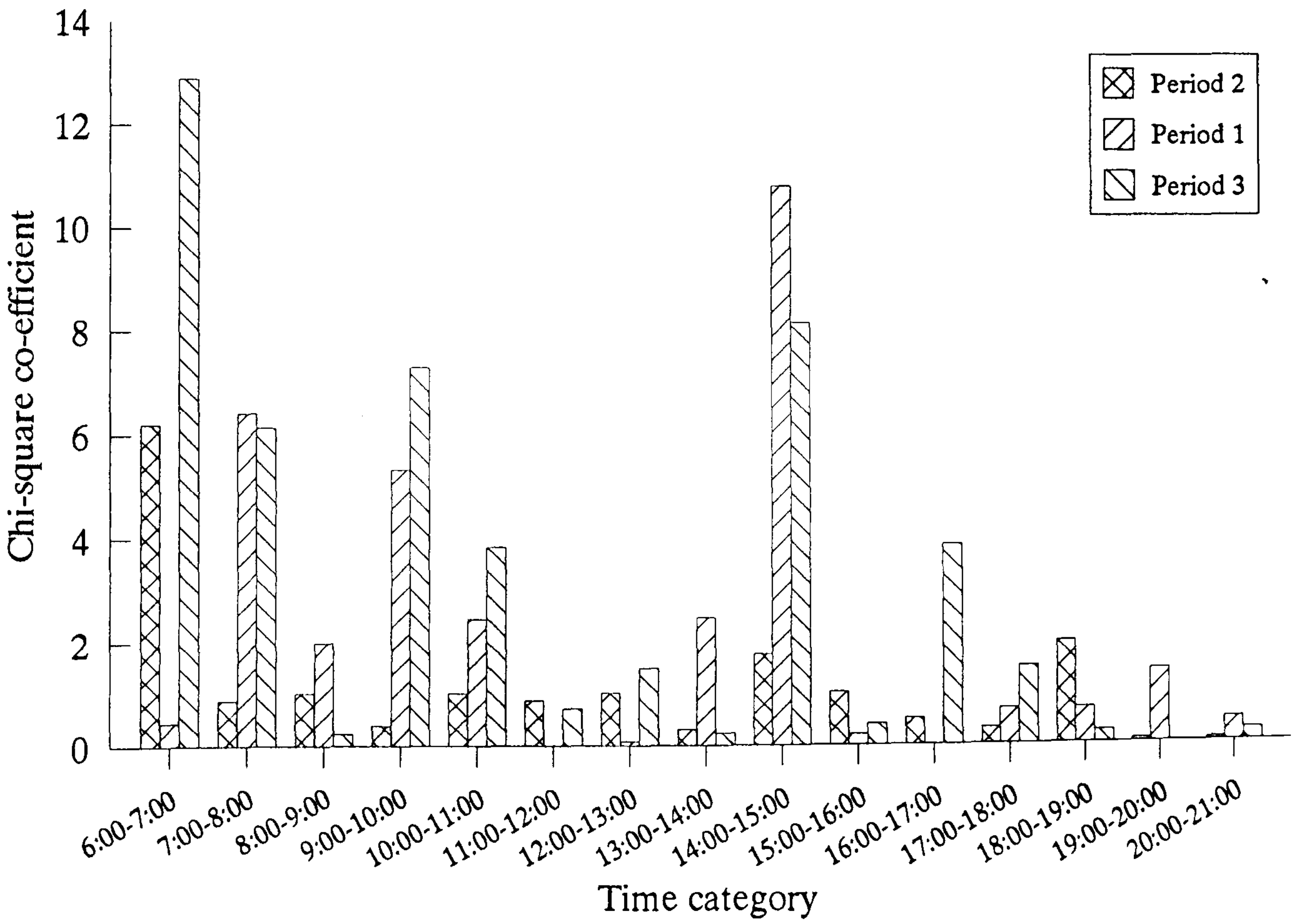


Figure 8.4b: Magnitude of difference between observed and expected frequency of milking during the day, using the Chi-square coefficient



3.4 Effect of treatment on time budgets for lying and feeding

3.4.1 Effect of the exit area feed on time budgets

The effect of feeding forage or concentrate in the exit area of the AMS on lying and feeding behaviour is shown in table 8.16. The data were derived from the full time budgets for eight cows for the least disturbed (by farm staff etc.) day in each of the three recording periods. The total time and bout length for lying and feeding were calculated using an analysis of variance. The data were blocked by individual cows nested within each period, with forage or concentrate fed in the exit area as the treatment structure. Details of the analysis can be seen in appendix 8b. The number of bouts was calculated as the total number of bouts for all the eight cows and analysed using the Wilcoxon matched pairs test.

Table 8.16 Effect of treatments on forage feeding and lying behaviour

Exit area feed: Bedded area:	Forage Concentrate	Concentrate Forage	s.e.m	Significance
Forage feeding:				
Total Time/day/cow (m)	209	289	33.6	3.1%
No. Bouts/cow/day	4.9	7.6	-	
Bout length (m)	38.9	37.4	3.48	67.0%
Lying:				
Total time/day/cow (m)	529	620	43.1	5.1%
No. bouts/cow/day	8.3	10.5	-	
Bout length (m)	61.7	61.6	5.59	97.7%

Forage feeding behaviour was modified by the treatments. When forage was fed in the bedded area and concentrate in the exit area, it resulted in significantly more feeding bouts (Wilcoxon matched pairs test, one-way, period 1 and 2 $p<1\%$, period 2 and 3 $p<5\%$, $n=8$), and a significantly longer total time spent feeding than when forage was fed in the exit area. The cows tended to spend longer lying, and lay more frequently (in the comparison between period 2 and 3) (Wilcoxon matched pairs test, one-way, period 1 and 2 $p>5\%$, period 2 and 3 $p<1\%$, $n=8$) when forage was fed in the bedded area and concentrate in the exit area than during the reverse treatment.

4 Discussion

4.1 Factors affecting attendance rate

Feeding concentrate in the exit area of the milking stall resulted in fewer attendances than when forage was fed there. However, this difference was largely due to a reduction in the diversion rate; there was little difference in the number of milkings. Feeding concentrate in the parlour did not appear to influence the level of visits, milkings or diversions. There were weak interactions between feeding forage/concentrate in the exit area and feeding/not feeding in the parlour. In all cases, the interaction resulted in fewer visits when the cows were fed concentrate in the exit area and nothing in the milking stall.

The increased attendance rates when the cows were fed forage in the exit area (but not in the bedded area) may have been for a number of reasons. It may have been because the forage was of such high quality (see chapter 2) that when fed in the exit area it was a powerful motivator and when in the bedded area satisfied the cow's hunger. Alternatively, in motivational terms the *need* to eat forage may be more pressing to the *want* to eat concentrate. Webster (1995) suggests that appetite level is derived from, among other things, metabolic hunger and gustatory qualities of the food. Metabolic hunger may produce a motivational need to eat, while palatability may produce a motivational want to eat. Therefore, when forage is fed in the exit area the cows may need to attend, to eat, to satisfy their metabolic hunger. When concentrate is fed in the exit area the cows may want to attend to satisfy their gustatory desires.

When the cows were fed concentrate in the exit area the system spent more of its active time in milking. In practice, this may allow more cows to be serviced by the system while keeping the time a cow has to wait to use the system low. This is further augmented by the removal of the peaks and troughs of attendance seen when feeding forage. The use of forage in the exit area may lead to long delays between the cow choosing to use the system to eat forage and her actually being able to reach the system. If this delay is long enough the cow may `give up' waiting and a milking opportunity will be missed.

The number of milkings that were actually performed for each cow were lower than expected, and some cows were only milked twice per day. The reason for this may have been that the system was only open for 15 hours per day. Winter (1993), in an experiment which fed forage in the exit area and concentrate in the milking stall. found a mean attendance rate of 5.9 visits/day with a mean milking rate of 3.2/day. In her experiment the system was available for 18 hours/day. Rossing et al. (1985), in an experiment where the cows were milked in an automatic concentrate feeder, showed that the cows would attend on average 5.4 times/day and be milked on average 4.0 times/day. All twenty of these cows were milked more than three times per day. Here the system was available for 24 hours/day.

When concentrate was fed in the exit area the cows attended the system less often but their yield did not suffer (see chapter 9). One cow persistently failed to attend the system and was manually collected at 21:00 to be milked. When collected she exhibited no fear or reluctance to enter the system. During the day, on treatment forage1 and 3, when she had no direct access to forage from the bedded area, she was often seen eating straw, consequently she lost condition. There were no obvious reasons for her non-attendance e.g. lameness, teat sores or mastitis.

There were other factors that affected how often the cows attended the system. Old and low ranking cows had a reduced frequency of visits. While the number of milkings was never significantly less, the number of diversions and hence the total number of visits was. This could be a potential problem since these effects may be worse when the number of cows being serviced by the AMS rises, as it may on commercial dairy farms. The results of attendance for the fearful/bold and old/young cows, however, need careful interpretation since there may be unequal effects of feeding or not feeding in the parlour.

The effect of rank suggests that there is competition to enter the system. Low ranking cows were less able to access the system than high ranking cows. This could exacerbate the effects on forage eating and lying behaviour of feeding forage in the exit area for low ranking cows

The effect of age on the number of visits is probably a manifestation of younger cows being more active than the older cows (Kempkens and Boxberger 1987).

4.2 Pattern of attendance

The pattern of attendance seemed to be quite clear when forage was fed in the exit area, and there were three peaks of attendance. The first early morning peak was probably in response to the presentation of fresh forage. The early afternoon (third) peak may have been in response to the forage being forked back up to the feed barrier during the shut down period between 13:00 and 13:30. The second peak is more difficult to understand. Since the effect was not seen when the cows were fed concentrate in the exit area however, it would imply that the cows' forage feeding behaviour was involved, possibly a sufficient time had elapsed since the early morning feed for the cows to begin to become hungry again. Winter (1993), feeding forage in the exit area and concentrate in the milking stall, also found three main peaks of attendance occurring at broadly similar times to those found in this trial.

The cows showed no evidence of visiting the system at the times that they would normally be milked (early morning at approximately 06:00 and in the afternoon at approximately 15:30). This is further evidenced by the lack of any recognisable peaks in attendance when the cows were fed concentrate in the exit area. Rossing et al. (1985), who fed concentrate in the milking stall, also found that the pattern of attendance was evenly spread throughout the day. This suggests that the cows experience of twice daily milking in a conventional parlour was not influencing their attendance pattern to a high degree.

4.3 Order of attendance

The cows only showed a significant order of attendance when they were fed concentrate in the exit area, although there was a suspicion of a similar trend in the third period when they were fed forage in the exit area. The lack of significance in the first period may have been a result of the cows not being settled into the routine. The order was not related to rank or age and since all the cows were of similar yield, it was probably not related to that either. Winter (1993) also found a milking order in a similar experiment.

The order of the cows was affected by parlour feeding, when the cows were fed in the parlour they entered earlier in the milking order than when they were not, suggesting that feeding the cows concentrate in the milking stall increased their motivation to enter the AMS.

4.4 Time budgets

The time budgets for forage feeding suggest that this behaviour was altered by the location of the forage. When the forage was in the exit area the cows fed for less time in total and had fewer feeding bouts. These data were similar to those found by Winter et al. (1992) and Ketelaar-de-Lauwere (1992). This suggests that the cows' feeding behaviour was altered and this can be explained in motivational theory. As the cost for a reward rises the number of times that the reward is taken may fall (McFarland 1977, Sibly and McFarland 1974). The animal may compensate for this by taking larger but fewer rewards, as with the doves mentioned in chapter 1 who increased their time spent feeding and drinking when a barrier was placed between the feeder and drinker (Larkin and McFarland 1978). In the AMS there is presumably a significantly higher cost of changing behaviour from feeding in the exit area to standing in the bedded area than there is for changing from feeding in the bedded area to standing in the bedded area. This is because, in the former, there is a one-way passage involved and, to reach the feed again, the cows have to enter the unpredictable and one way AMS which may impose a cost.

The position of the concentrate and forage modified the cows' forage eating and lying behaviour. The total time spent eating forage was reduced by 28%, and the number of forage feeding bouts was reduced by approximately one third, when forage was fed in the exit area as opposed to the bedded area. At the same time the total time spent lying was reduced by 15% and the number of lying bouts reduced by about one fifth under the same treatment. Changes in feeding and resting behaviour of this sort may prove detrimental to the cows' welfare if Webster's hypothesis (1995), that cows are both hungry and tired at the same time, due to the competing demands to rest and eat, is right. If cows could be shown to have reduced forage intake when forage is fed in the exit area of the AMS, then this method may reduce the cow's welfare by increasing her risk of metabolic disease, and reduce profitability by decreasing yield and increasing health costs.

5 Conclusions

There was no detrimental effect of feeding concentrate in the exit area as opposed to forage, apart from a slightly lower milking rate. There were, however, significant advantages to doing so. The attendance was more evenly spread through the day and forage feeding and lying behaviour were unaffected. There is also the potential to feed the cows concentrate differentially to change their attendance rates.

Feeding in the parlour did not affect attendance as a main effect. However, there was an interactive effect; when concentrate was fed in the exit area and not fed in the parlour they attended less often on any other treatment combination.

Old and low ranking cows had lower attendance rates than young or high ranking cows.

The cows showed significant signs of disrupted feeding and resting behaviour when the forage was only accessible by entering the AMS.

Appendix 8

In the following tables 'silconc' refers to the treatment of feeding silage or concentrate in the exit area. 'fnf' refers to feeding or not feeding in the parlour. * indicates an interaction, and / indicates a block nested within the preceding block. In the blocking structures `period' refers to the three experimental periods (forage1, conc2, forage3), `groups' to the two groups of seven cows, and `animals' to the 14 individual cows. `Events' refers to the particular day, one in each period, over which data were collected.

`Stratum' refers to the parts of the blocking structure which were considered in the analysis. For example, in table 8a.1 comparisons between feeding silage or concentrate (silconc) occur between the three periods, whereas comparisons between feeding or not feeding in the parlour (fnf) occur between the periods but also between the groups. There was no treatment that occurred in the period/group/animal stratum.

Because of constraints in the experimental design, the residual degrees of freedom are small, for example in table 8a.1, the residual in the period stratum has one degree of freedom, and this can be calculated as follows. There are three periods giving a total of two degrees of freedom for that stratum (n-1). Silconc has two options (silage or concentrate) and therefore accounts for one of those degrees of freedom (again, n-1), leaving one degree of freedom for the residual. The consequences of this are to reduce the sensitivity of the analysis, i.e. differences in attendance between feeding silage and concentrate would have to be larger to become significant than if the residual had a greater number of degrees of freedom.

Appendix 8a Effect of location of forage and forage on aspects of attendance

8a.1 Analysis of variance for the effect of the location of forage and forage on total number of visits

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period stratum				
Silconc	1	297.19	520.08	2.8%
Residual	1	0.57	0.11	
Period/group stratum				
fnf	1	24.38	4.74	27.4%
Silconc*fnf	1	485.76	94.45	6.5%
Residual	1	5.14	0.10	
Period/group/animal stratum	36	1842.86		
Total	41	2655.90		

8a.2 Analysis of variance for the effect of the location of forage and forage on total number of milkings

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period stratum				
Silconc	1	5.250	147.00	5.2%
Residual	1	0.036	0.11	
Period/group stratum				
fnf	1	4.667	14.52	16.3%
Silconc*fnf	1	44.298	137.81	5.4%
Residual	1	0.321	0.09	
Period/group/animal stratum	36	127.714		
Total	41	182.286		

8a.3 Analysis of variance for the effect of the location of forage and forage on total number of diversions

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period stratum				
Silconc	1	223.44	695.15	2.4%
Residual	1	0.32	0.11	
Period/group stratum				
fnf	1	7.71	2.67	35.0%
Silconc*fnf	1	236.68	81.81	7.0%
Residual	1	2.89	0.09	
Period/group/animal stratum	36	1209.43		
Total	41	1680.48		

Appendix 8b Effect of location of forage on forage feeding and lying times

8b.1 Analysis of variance for the effects of the location of the forage (exit area or bedded area) on the total forage feeding time of the cows.

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Animals stratum	7	41620	0.99	
Animals/event stratum				
Silconc	1	34240	5.69	3.1%
Residual	15	90215		
TOTAL	23	166075		

8b.2 Analysis of variance for the effects of the location of the forage (exit area or bedded area) on the total lying time of the cows.

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Animal stratum	7	80685	1.17	
Animal/event stratum				
Silconc	1	44287	4.48	5.1%
Residual	15	148341		
TOTAL	23	273313		

8b.3 Analysis of variance for the effects of the location of the forage (exit area or bedded area) on the length of the forage feeding bouts

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Animal stratum	7	13332.2	5.68	
Animal/event stratum				
Silconc	1	75.9	0.18	67.0%
Residual	133	55219.7		
TOTAL	141	68627.9		

8b.4 Analysis of variance for the effects of the location of the forage (exit area or bedded area on the length of the lying bouts

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Animal stratum	7	14556.0	1.52	
Animal/events stratum				
Silconc	1	1	0.00	97.7%
Residual	209	333818		
TOTAL	217	348376		

CHAPTER 9

EFFECT OF FEED TYPE AND LOCATION, AGE AND FEARFULNESS ON DAIRY COWS' TRANSIT TIME THROUGH AN AUTOMATIC MILKING SYSTEM

1 Introduction

The rapidity with which cows move through the AMS determines the number of cows per hour who can be milked. Low throughputs will either mean that additional units will have to be purchased or cows will have to queue to enter the system.

There are a number of factors which may influence the time it takes a cow to move through parts of an AMS. 1) The system has points where the cow has to wait for gates to open. Stopping a cow may lead to delays before she starts moving again. These stopping points occur in the ID stall, the milking stall and, in the present experiment, at the holding gate. 2) The cow may feel some uncertainty from not knowing if she will be accepted to be milked or diverted. Winter (1993) and Ketalaar-de-Lauwere (1992) have both suggested that this uncertainty may be aversive to the cow. Winter also showed that the introduction of the diversion gate caused the cows to increase the time spent idling in the ID stall. 3) The presentation of food rewards around the system may affect how quickly the cows move. If a cow associates the milking stall with being fed but is diverted along the diversion race, she may idle in the ID stall anticipating that she will be allowed to enter the milking stall eventually (Winter 1993). The reverse may be true if she is being rewarded in the exit area but not in the milking stall. 4) In the AMS, at present, the cow has a clear view of her surroundings through the sides of the races. Grandin (1995) has suggested that for good animal flow characteristics the best races are those which curve gently, have opaque sides, are well and evenly lit and do not have differences in floor type. 5) The cows may enter the system for reasons other than to be milked or fed. Low ranking cows may enter the system to escape the aggressive attentions of other cows, and, as such, they may be less likely to move quickly through the AMS. Other factors might include the state of the cow's hooves and legs and how old, fearful or curious she is. Fearful cows may move through the system slower than bold cows because they find it more aversive. Old cows may move through the system slower than young cows because of accumulated leg and hoof disorders.

A passive solution to the problem of slow movement through the system is to use various rewards located around the system. Winter (1993) showed that cows took longer to be diverted and exit the milking stall when fed concentrate in the parlour but less time to enter. Metz-Stefanowska et al. (1992) reported that 38% of the time cows had to be encouraged out of the milking stall after milking in an experiment that involved feeding concentrate in the parlour.

There were two obvious places where cows could be fed in the AMS. In the milking parlour the cows could either be fed or not fed concentrate, and in the exit area they could be fed concentrate or forage. This experiment tested these alternatives on the time taken to move through various parts of the system. In the first part of this experiment the cows were fed different amounts of concentrate in the exit area and the milking stall, to study the effect on time taken to exit the parlour after milking. In the second part of this experiment the cows were fed or not fed concentrate in the parlour and fed concentrate or forage in the exit area. The effect of age and fearfulness (as defined in chapter 7) on time taken to move through the system was also assessed. This chapter was the second in a series of three (see chapters 8 and 10) looking at factors affecting attendance at, and behaviour in, the AMS.

2 Materials and Methods

2.1 General Method

In the first part of this experiment the cows were milked in the AMS for the afternoon milking only. The cows were milked in the farm's main milking parlour for the morning milking but housed in the bedded area of the AMS. Initially, teat cup attachment and removal were automatic with the cows being let in and out of the system and their teats cleaned manually. When the robot was damaged however, the operation became entirely manual. In the exit area the cows were fed manually using a simulated automatic concentrate feeder. The location and a photograph of the feeder are shown in fig 9.1a and b.

The general method for the second part of this experiment is the same as given in Chapter 8.

2.2 The experimental design and data recording

2.2.1 Part 1

Eighteen cows were divided into three groups of six. There were three five-day periods and three treatments. The treatments comprised feeding 2kg of concentrate in the parlour and nothing in the exit area (parlour2), feeding 1kg of concentrate in the parlour and 1kg of concentrate in the exit area (parlour1), and feeding nothing in the parlour and 2kg in the exit area (parlour0). The experiment was a latin-square design as shown in table 9.1.

Table 9.1 Experimental design for part 1: kg of food fed in each location

		Period 1	Period 2	Period 3
Group 1-	Exit area:	2	1	0
	Milking stall:	0	1	2
Group 2-	Exit area:	1	0	2
	Milking stall	1	2	0
Group 3-	Exit area:	0	2	1
	Milking stall	2	0	1

The time taken for the cows to exit was recorded manually. Recording started as the milking stall exit gate opened and finished when the cow finished breaking the light

Figure 9.1a: Position of simulated automatic concentrate feeder in part 1

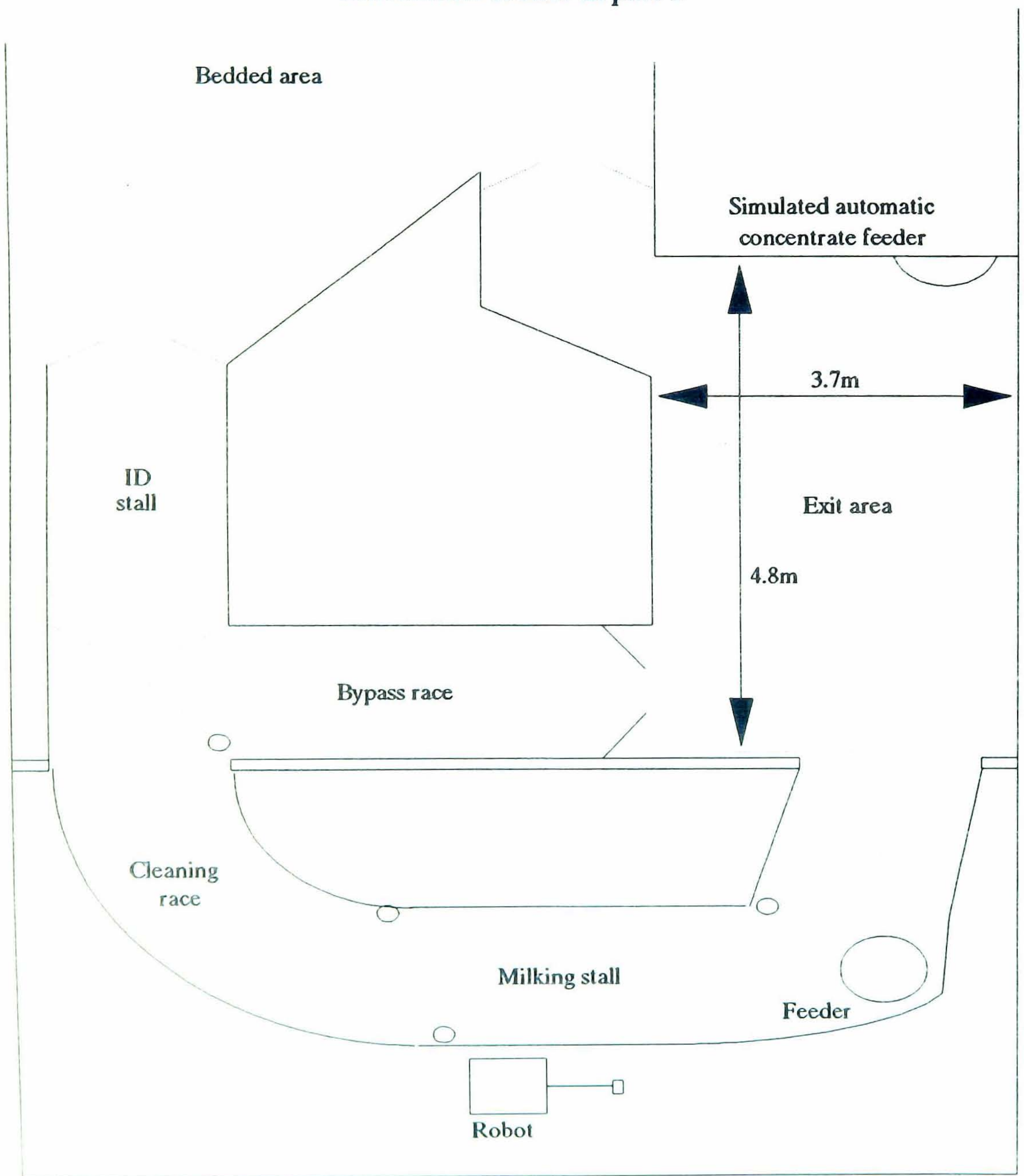


Figure 9.1b: Photograph of simulated Automatic concentrate feeder

beam across the exit of the parlour (shown as MSEA in figure 9.2). The time taken to exit for the last day of each period was used in the analysis.

2.2.2 Part 2

The experimental design is the same as described in Chapter 8. For all attendances the time taken to move through four stages was recorded. These stages were; 1) Moving from the ID stall into the cleaning race and up to the holding gate, *'IDHG'* (5m). 2) Moving from the holding gate fully into the milking stall, *'HGMS'* (4m). 3) The time taken for the cows to leave the milking stall, *'MSEA'* (4.5m). Finally 4) the time taken for the cows to move through the diversion race, *'Diversion'* (5m). In the first three stages the recording was manual. For the diversion stage, the time was recorded automatically. For the IDHG, HGMS and MSEA stages, the cows were allowed 180s to complete each stage. If they failed to do this they were encouraged through the stage and their time recorded as 180+s. This method was adopted to prevent an individual cow from blocking the system for excessive periods. In the diversion stage, the cows were not encouraged through if they idled for longer than 180s since this would have disturbed any cows feeding in the exit area. The various stages and the position of the feeders are shown in figure 9.2.

2.3 The animals

For the first part of this experiment 18 cows were selected from the herd at Cheseridge Farm, belonging to the Institute for Animal Health, Compton. For the second part of this experiment 14 cows were selected. These were animals who were thought to have appropriate udder conformation for accurate teat-cup attachment. Details of the animals used in the first part of the experiment are given in table 9.2 and 9.3 where DIM indicates days in milk.

Figure 9.2: Four stage and feeder locations in part 2

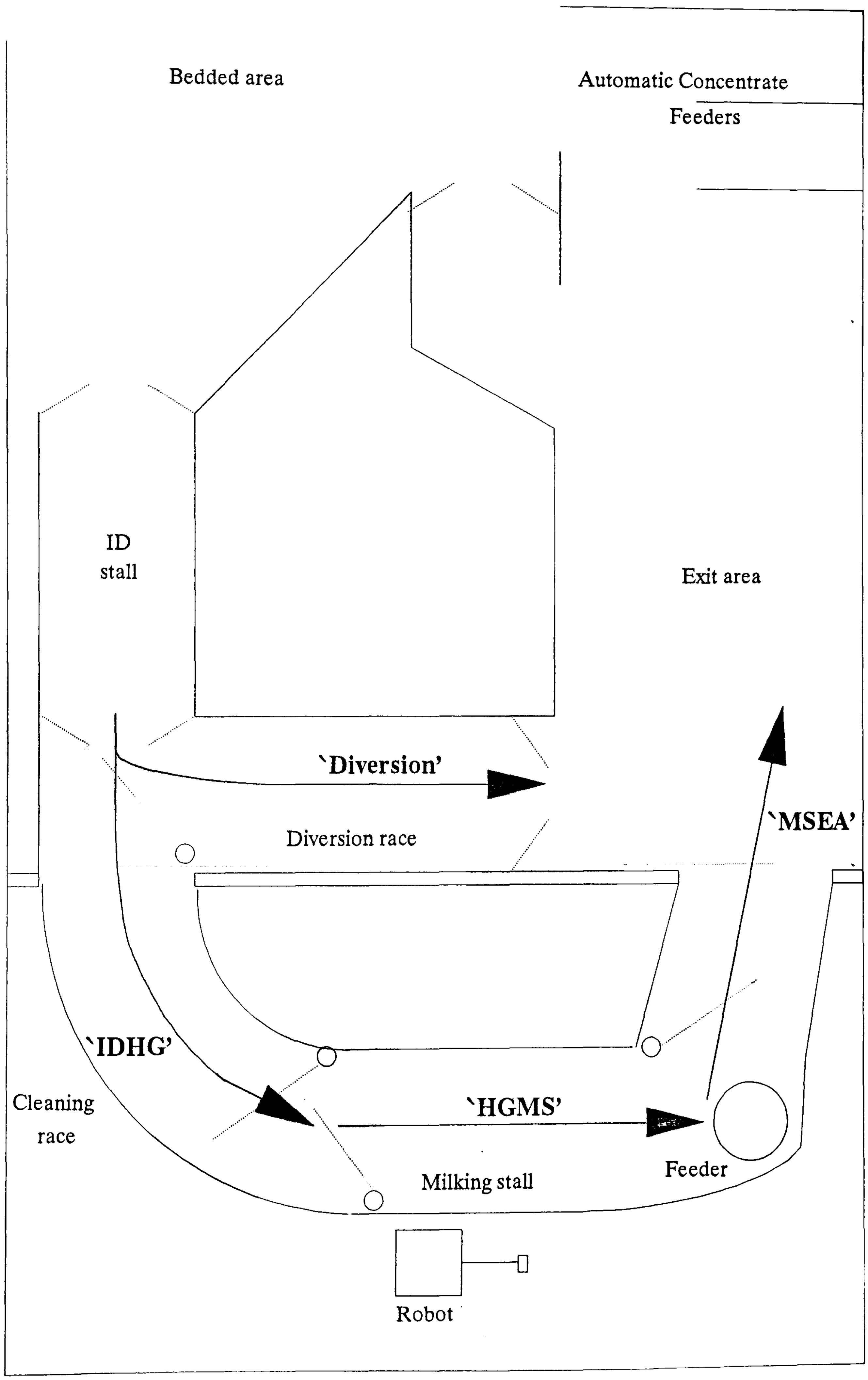


Table 9.2 Cow data for part 1

Cow	Group	Yield (l)	Parity	DIM (d)
A905	1	22.1	5	176
1033	1	24.2	1	154
9032	1	18.9	3	179
1070	1	21.5	1	143
1004	1	23.8	1	180
1182	1	24.1	1	123
1107	2	24.5	1	146
1035	2	20.7	1	138
1138	2	23.6	1	161
1003	2	22.9	1	128
9587	2	19.7	3	135
0029	2	25.0	2	130
1082	3	22.7	1	146
1040	3	24.1	1	128
1026	3	23.8	1	158
9026	3	23.9	3	160
1128	3	20.1	1	172
1176	3	22.9	1	142

Table 9.3 Group averages for part 1

	Mean Yield (l) (s.d)	Mean parity	Mean DIM (s.d.)
Group 1	22.43 (2.06)	2.0	159.17 (23.27)
Group 2	22.73 (2.12)	1.5	139.67 (12.24)
Group 3	22.92 (1.49)	1.3	151.00 (15.53)

Details of the animals in the second part of the experiment are given in chapter 7.

2.4 Training

2.4.1 Experiment 1

Ten days before the start of the experiment the cows were housed together in the bedded area of the AMS. For the first five days of this period they were encouraged through the system and fed concentrate in the parlour and the exit area but milked in the farm's main parlour. For the final five training days, the cows were milked in the AMS milking stall for the afternoon milking.

2.4.2 Experiment 2

The training for the second part of the experiment is the same as given in chapter 8

2.5 Analysis

All analyses were performed using analysis of variance. In the first analysis the timings for the last day of each five day period were analysed, the data were blocked by individual animals nested within groups which were nested within period. In part 2 the data were blocked by individual animals nested within each of the three recording days of each period, which were nested within groups, which were nested within the periods. The effects of age and fearfulness were analysed similarly but only using particular cows.

3 Results

3.1 Part 1 Effect of feeding in the parlour and exit area on time taken to exit the milking stall

The analysis was performed using an analysis of variance blocked by period, group and individual animals (nested in the reverse order) with the feed level in the parlour as the treatment. The timings were transformed by taking their natural logarithms to approximate a normal distribution. Details of the analysis are shown in appendix 9a. A summary of this analysis is shown in table 9.4

Table 9.4 Effect of feeding location on time taken to exit the milking stall. Values expressed as their natural logarithms to allow comparison with the s.e.d. Bracketed figures indicate back transformed means in seconds

	Parlour0	Parlour1	Parlour2	s.e.d
Timings, log s (s)	1.86 (6.44)^{a}	1.95 (7.00)^{a}	3.63 (37.83)^{b}	0.01

(Where latencies with different superscripts differ significantly ($p<1\%$)

When the cows were fed in the exit area they left the parlour significantly faster regardless of whether they had been fed there.

3.2 Part 2 Effect of feeding in the parlour and feeding forage or concentrate in the exit area on timings

The analysis for part 2 was performed using an analysis of variance. The data were transformed by taking their natural logarithms to approximate a normal distribution. The diversion data were incomplete (26 out of 126 data points were missing) but enough data were collected for the analysis of variance to be completed. The experimental data were blocked by period, group, day and animal (nested in the reverse order). The treatment structure was forage or concentrate fed in the exit area and fed or not fed concentrate in the parlour. The tables in this section show the main effects of feeding in the parlour and food type in the exit area, followed by their interactive effects. More detailed tables of the analyses of variance are shown in appendix 9b. Figure 9.3a and b show the main and interactive effects of the treatments on the time taken to progress through the four stages.

Figure 9.3a: Graph showing main effects of treatments in part 2

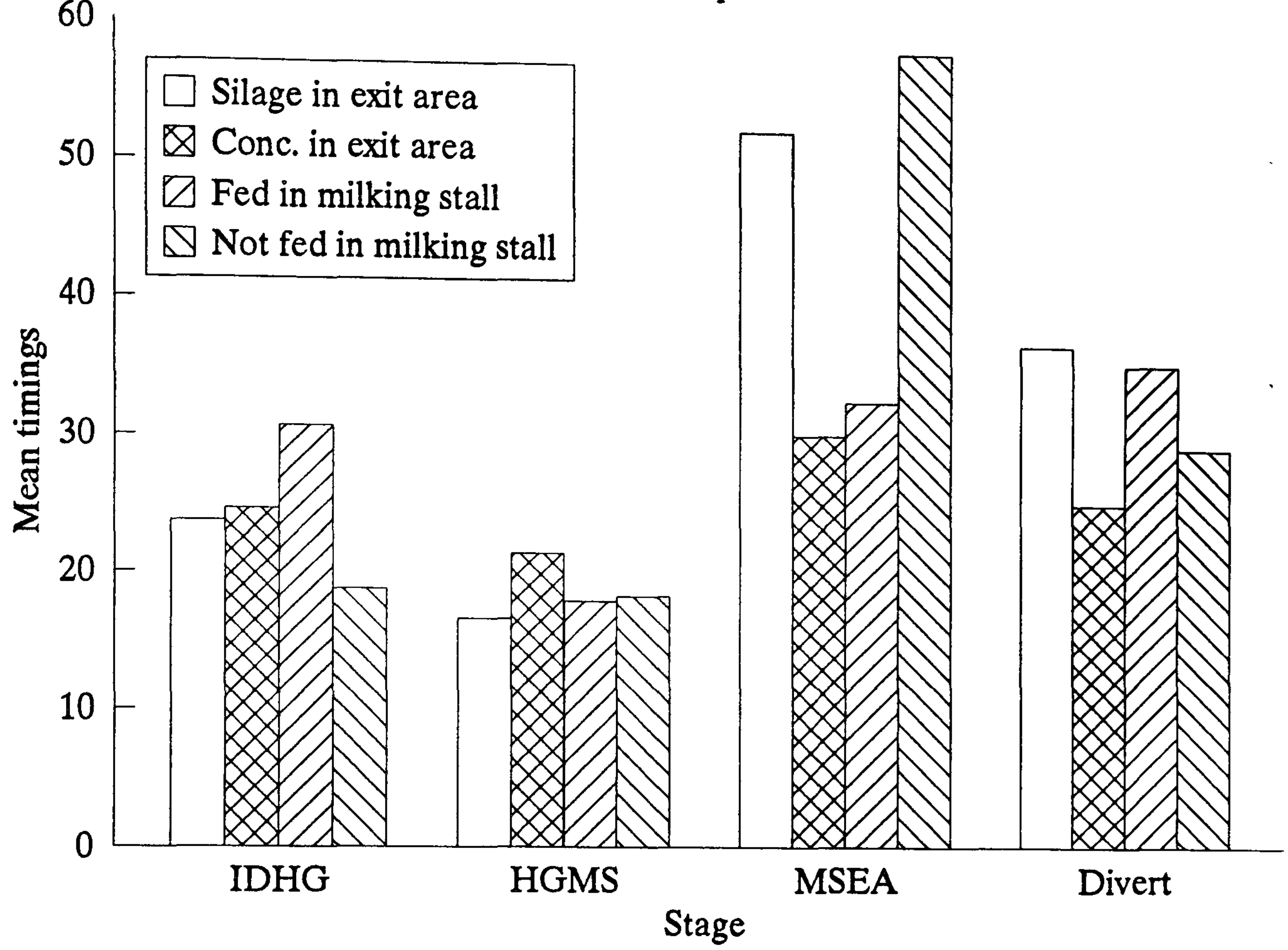
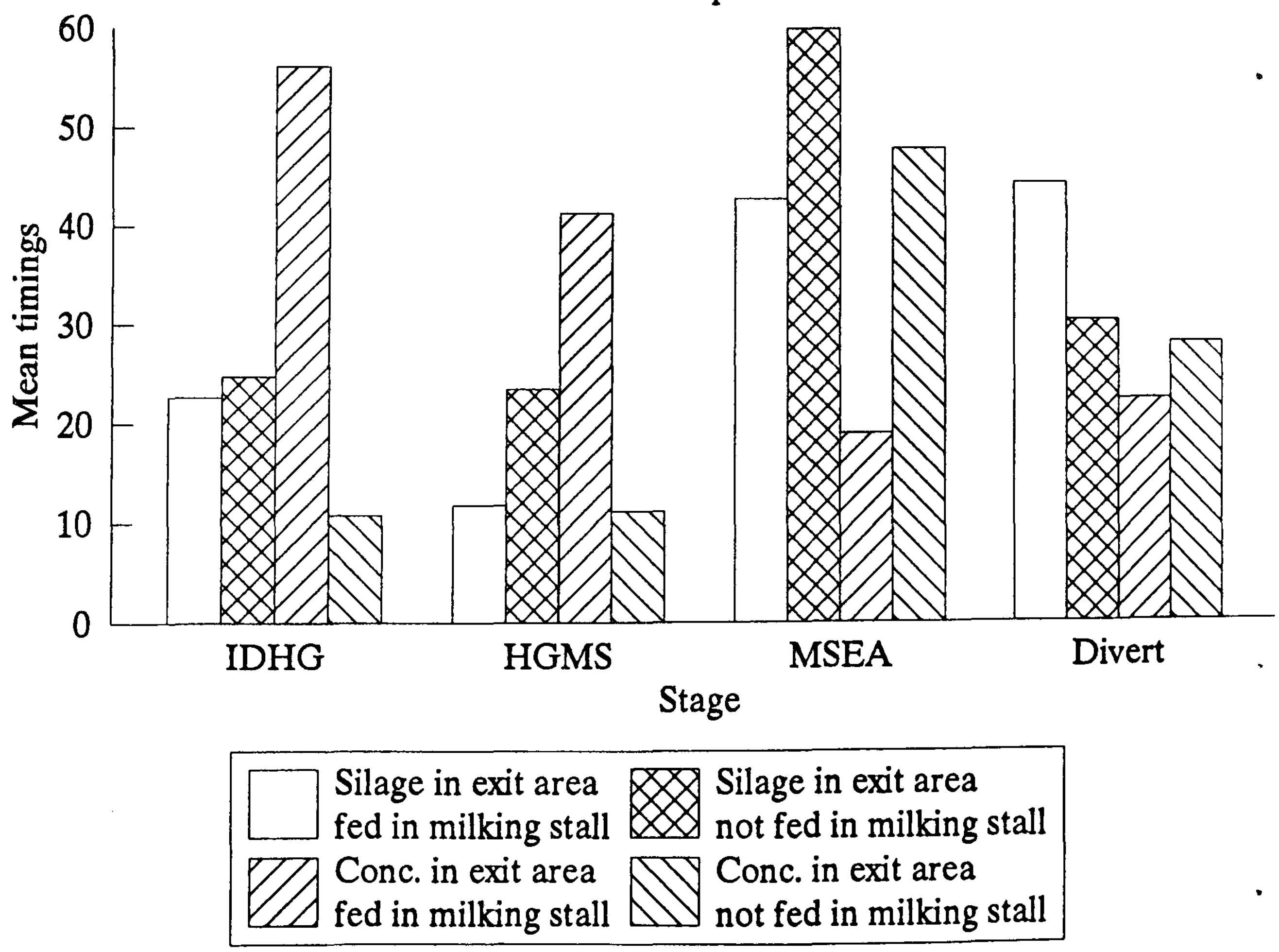


Figure 9.3b: Graph showing interactive effect of treatments in part 2



3.2.1 Effect of exit area feed type and parlour feeding on time taken to move through the system.

Table 9.5 shows the effect of the two treatments on the time taken to move from the ID stall to the holding gate.

Table 9.5 Mean time (s) to move through the IDHG stage showing the main effect of individual treatment and interactive effects. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Main effects	Latency	s.e.d	Sig
Forage in exit area	3.17 (23.69)	0.02	27.2%
Concentrate in exit area	3.20 (24.58)		
Fed in parlour	3.41 (30.14)	0.16	20.3%
Not fed in parlour	2.93 (18.82)		
Interactions	Fed in parlour	Not fed in parlour	sig.
Forage in exit area	3.12 (22.67)[a,c]	3.21 (24.75)[a,d]	11.7%
Concentrate in exit area	4.03 (56.20)[b,c]	2.37 (10.75)[b,d]	

(Subscript letters following interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; a=0.14, b=0.14, c=0.23, d=0.23)

There were no effects of either feeding in the parlour or the type of exit area food on the time taken to negotiate the IDHG stage.

The effects of the treatments on the time taken to move through the HGMS stage are shown in table 9.6.

Table 9.6 Mean time (s) to move through the HGMS stage showing individual treatment and interactive effects. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Main effects	Latency	s.e.d	Sig
Forage in exit area	2.81 (16.61)	0.69	17.2%
Concentrate in exit area	3.06 (21.37)		
Fed in parlour	2.88 (17.89)	1.08	53.3%
Not fed in parlour	2.90 (18.25)		
Interactions	Fed in parlour	Not fed in parlour	sig.
Forage in exit area	2.88 (11.79)^{a,c}	3.15 (23.41)^{a,d}	1.5%
Concentrate in exit area	3.72 (41.22)^{b,c}	2.41 (11.08)^{b,d}	

(Subscript letters following interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a}=0.06, ^{b}=0.09, ^{c}=0.03, ^{d}=0.03)

There was no effect of feeding in the parlour or feeding forage or concentrate in the exit area on the time taken to move through the HGMS stage. There was a significant interactive effect in that when the cows were 'fed concentrate in the exit area and the parlour' and 'fed forage in the exit area and in concentrate in the parlour' they tended to enter the milking stall slower than the other two treatments.

The effect of the treatments on the time taken to move through the MSEA stage are shown in table 9.7.

Table 9.7 Mean time (s) to move through the MSEA stage showing individual treatment and interactive effects. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Main effects	Latency	s.e.d	Sig
Forage in exit area	3.96 (52.25)	0.27	29.3%
Concentrate in exit area	3.41 (30.14)		
Fed in parlour	3.48 (32.59)	0.14	15.3%
Not fed in parlour	4.06 (58.03)		
Interactions	Fed in parlour	Not fed in parlour	sig.
Forage in exit area	3.75 $(42.73)^{a,c}$	4.16 $(63.88)^{a,d}$	33.2%
Concentrate in exit area	2.94 $(18.97)^{b,c}$	3.87 $(47.85)^{b,d}$	

(Subscript letters following interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a}=0.25, ^{b}=0.36, ^{c}=0.22, ^{d}=0.21)

There were no effects of either treatment on the time taken to move through the MSEA stage.

The effect of the treatments on the time taken to move through the diversion race are shown in table 9.8.

Table 9.8 Mean time (s) to move through the diversion stage showing individual treatment and interactive effects. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Main effects	Latency	s.e.d	Sig.
Forage in exit area	3.60 (36.78)	0.01	1.3%
Concentrate in exit area	3.22 (25.15)		
Fed in parlour	3.57 (35.41)	0.14	9%
Not fed in parlour	3.38 (29.28)		
Interactions	Fed in parlour	Not fed in parlour	Sig.
Forage in exit area	3.79 $(44.48)^{a,c}$	3.42 $(30.45)^{a,d}$	5.1%
Concentrate in exit area	3.11 $(22.44)^{b,c}$	3.34 $(28.22)^{b,d}$	

(Subscript letters following interaction means refer to s.e.ds. Figures with the same superscripts have the following s.e.ds; ^{a}=0.03, ^{b}=0.04, ^{c}=0.03, ^{d}=0.03)

There was a significant effect of feeding forage or concentrate in the exit area. when forage was fed here the cows moved through the diversion race slower than when concentrate was. There was some suggestion that feeding the cows in the parlour also increased the diversion time but this was not significant. When the cows were fed forage in the exit area and also fed in the parlour they tended to spend longer negotiating the diversion race than for the other treatments.

3.2.2 Effect of age on time taken to move through the various stages

Data for the three oldest and youngest cows were used in this analysis. The data were blocked by period, day and animal (and nested in the reverse order). The data were transformed by taking their natural logarithms to approximate a normal distribution. A summary of the analysis is shown in table 9.9. The analysis of variance is shown in appendix 9c.

Table 9.9 Effect of age on the time taken to negotiate the four stages. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Stage	Young group	Old group	s.e.d.	Significance
IDHG	2.83 (16.95)	3.65 (38.47)	0.25	<1%
HGMS	2.99 (19.93)	2.73 (15.39)	0.18	16.0%
MSEA	3.03 (20.70)	3.96 (52.46)	0.21	<1%
Diversion	3.49 (32.85)	3.35 (28.45)	0.17	39.0%

There was a significant difference between the time taken for old and young cows to negotiate the IDHG and MSEA stages. The young cows moved through these stages quicker than the old cows.

3.2.3 Effect of Fearfulness on time taken to negotiate the various stages

The data were analysed in a similar manner to the age analysis except that the data for the five fearful and four bold cows was used.

A summary of the data is shown in table 9.10. Details of the analysis are shown in appendix 9d.

Table 9.10 Effect of fearfulness on time taken to move through the various stages. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds

Stage	Fearful	Bold	s.e.d	Significance
IDHG	3.54 (34.47)	2.74 (15.49)	0.19	<1%
HGMS	3.05 (21.20)	2.90 (18.23)	0.20	68.0%
MSEA	3.96 (52.35)	3.72 (41.22)	0.21	88.2%
Diversion	3.70 (40.45)	3.24 (25.64)	0.16	<1%

Fearfulness had a highly significant effect on the time it took the cows to move through the IDHG and diversion stages. Fearful cows moved through these stages slower than the bold cows.

4 Discussion

4.1 Part 1 Effect of feeding or not feeding in the milking stall and exit area on time taken to exit the milking stall.

This experiment showed that if cows were fed in the exit area of the milking stall they left faster, irrespective of whether they were being fed in the parlour. The longest exit time when the cows were being fed in the exit area was 18s. Winter (1993) showed that feeding cows in the parlour increased their exit times when they were also fed forage in the exit area. This experiment suggests that this may not be the case when they are fed concentrate in the exit area.

There were five cows who left the parlour quickly, even when they were not being fed in the exit area. Presumably these cows either expected a food reward in the exit area or found the milking process mildly aversive.

This experiment suggested that it may be possible to use concentrate as a lure to attract cows out of the milking stall. This method may also be applicable to moving the cows through other parts of the system.

The reasons why cows who were not being fed in the exit area but fed in the milking stall remained in the stall may have been because they were reluctant to leave an area from where they had been rewarded. Alternatively, the cows may have been content to `loaf' in the milking stall where they had a good view of the barn and were under no social pressures, this may have been exacerbated by the cows being held in the milking stall for approximately five minutes while being milked.

4.2. Part 2 Effect of type of feed in the exit area and feeding or not in the parlour.

There appeared to be no main effects of either feeding in the parlour or the type of food fed in the exit area on the time taken to negotiate the IDHG, HGMS or MSEA stages. The cows did, however, move through the diversion race quicker when they were fed concentrate than when they were fed forage in the exit area. This may be for one of two reasons. First, the motivation to reach the concentrate may have been higher than the motivation to reach the forage. Alternatively, when the cows were fed concentrate in the exit area the attendance pattern through the day was less variable than when they were fed forage (see chapter 8). This implies (and it was the author's impression) that the number of cows in the exit area was more variable and, at times, more crowded when they were fed forage than when they were fed concentrate. Therefore, the increased latency when forage was fed in the exit area may simply have been because the exit area was overcrowded. There was also a significant interactive effect, when the cows were fed in the parlour and fed forage in the exit area they moved through the diversion stage slower than when they were either fed concentrate in the exit area or not fed in the parlour. This tends to suggest that when the cows were being fed in the parlour, but were diverted, the prospect of a forage reward in the exit area was less rewarding than the prospect of a concentrate reward either in the exit area or the parlour.

There was also another interactive effect in the HGMS stage. When the cows were fed concentrate in the parlour while forage was being fed in the exit area and when they were not being fed in the parlour and fed concentrate in the exit area, they entered the milking stall quicker than when they were being fed concentrate in the parlour and the exit area or when they were not being fed in the parlour and fed forage in the exit area. This effect is difficult to interpret since we would have expected that when fed concentrate in the parlour and the exit area, the cows would have entered at the same speed or quicker than when not fed concentrate in the parlour and forage in the exit area.

4.2.1 Effect of age on latencies

The three younger cows appeared to move through the IDHG and MSEA stages quicker than the three older cows. This may have been related to the findings of Kempkens and Boxberger (1987) who found that younger cows move around housing more than old cows; the old cows may simply have been moving slower than the young cows.

4.2.2 Effect of fearfulness on latencies

The five fearful cows moved through the IDHG and diversion race slower than the four bold cows. This hesitancy in entering the parlour may have been because they found it frightening. Either the noise, smell, lighting or the necessity to be in close proximity to the operator may have been aversive. The reluctance to negotiate the diversion race may have been for the reasons mentioned above in that, at times, the exit area became crowded. Pushing into this crowd may have been less aversive to bold cows than fearful cows.

5 Conclusions

Feeding concentrate in the exit area of the milking stall caused the cows to exit quicker than when they were fed nothing, regardless of whether they were fed in the parlour. This supports the hypothesis that the cows can be lured through the system using food.

Feeding in the parlour or the type of food in the exit area appeared to have no main effects on the time taken to move through the stages of the milking system. There was an effect for the diversion stage however, when the cows were fed concentrate in the exit area their transit time was slower than when they were fed forage.

Fearful and old cows took longer to progress through some stages than bold or younger cows.

Appendix 9

In the following tables 'Silconc' refers to silage or concentrate fed in the exit area. 'Fnf' refers to feeding or not feeding in the parlour. * indicates an interaction and / indicates a block nested within the preceding block

Appendix 9a

Analysis of variance for Part 1: Effect of feeding or not feeding in the parlour and the exit area on time taken to exit from the milking stall.

Table 9a.1 Effect of feed level in the parlour and exit area on time taken to exit the milking stall.

Variation Source	d.f.	Sum squares	Variance ratio	Sig
Period stratum	2	0.0122	0.52	
Period/group stratum				
feed level	2	4.2862	182.23	<1%
Residual	4	0.0470	0.37	
Period/group/animal stratum	45	1.4476		
Total	53	5.7931		

Appendix 9b

Analyses of variance for Part 2: Time taken to move between the various stages as affected by feeding in the parlour and type of food in the exit area.

Table 9b.1 Analysis of Variance for the time taken to negotiate the IDHG stage

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period Stratum				
Silconc	1	0.0614	4.81	27.2%
Residual	1	0.0128	0.02	
Period/group stratum				
fnf	1	6.9888	9.19	20.3%
silconc*fnf	1	22.0679	29.00	11.7%
Residual	1	0.7609	2.96	
Period/group/day stratum	12	3.0844	0.34	
Period/group/day/animal stratum	108	81.0945	0.75	
TOTAL	125	114.0705		

Table 9b.2 Analysis of Variance for the time taken to negotiate the HGMS stage

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period Stratum				
Silconc	1	1.7805	13.05	17.2%
Residual	1	0.1365	9.09	
Period/group stratum				
fnf	1	0.0122	0.81	53.3%
silconc*fnf	1	28.0235	1866.40	1.5%
Residual	1	0.0150	0.05	
Period/group/day stratum	12	3.5531	0.76	
Period/group/day/animal stratum	108	42.0119		
TOTAL	125	75.5327		

Table 9b.3 Analysis of Variance for the time taken to negotiate the MSEA stage

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period Stratum				
Silconc	1	8.4839	4.08	29.3%
Residual	1	2.0780	3.28	
Period/group stratum				
fnf	1	10.4728	16.55	15.3%
silconc*fnf	1	1.9139	3.02	33.2%
Residual	1	0.6329	2.01	
Period/group/day stratum	12	3.7841	0.34	
Period/group/day/animal stratum	108	99.7087		
TOTAL	125	127.0743		

Table 9b.4 Analysis of Variance for the time taken to negotiate the Diversion stage

Variation Source	d.f.	Sum squares	Variance ratio	Sig.
Period Stratum				
Silconc	1	4.4789	2274.83	1.3%
Residual	1	0.0020	0.10	
Period/group stratum				
fnf	1	0.9592	49.21	9.0%
silconc*fnf	1	3.0147	154.65	5.1%
Residual	1	0.0195	0.06	
Period/group/day stratum	12	4.2384	1.04	
Period/group/day/animal stratum	108	27.8187	0.75	
TOTAL	125	35.5575		

Appendix 9c

Table 9c.1 Analysis of Variance for the effects of age on time taken to negotiate the IDHG stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	0.0041	0.01	
Period/Day stratum	6	1.4655	0.28	
Period/Day/Animal stratum				
Age	1	9.1591	10.52	<1%
Residual	44	38.3226		
Total	53	48.9512		

Table 9c.2 Analysis of Variance for the effects of age on time taken to negotiate the HGMS stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	0.7913	0.71	
Period/Day stratum	6	3.3384	1.27	
Period/Day/Animal stratum				
Age	1	0.8971	2.04	16.0%
Residual	44	19.3019		
Total	53	24.3286		

Table 9c.3 Analysis of Variance for the effects of age on time taken to negotiate the MSEA stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	9.9350	18.24	
Period/Day stratum	6	1.6343	0.47	
Period/Day/Animal stratum				
Age	1	11.6939	20.10	<1%
Residual	44	25.5957		
Total	53	48.8589		

Table 9c.4 Analysis of Variance for the effects of age on time taken to negotiate the Diversion stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	3.8044	19.21	
Period/Day stratum	6	0.5943	0.27	
Period/Day/Animal stratum				
Age	1	0.2803	0.76	39.0%
Residual	38	14.0692		
Total	47	17.4217		

Appendix 9d

Table 9d.1 Effect of fearfulness on time taken to negotiate the IDHG stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	0.4949	2.81	
Period/Day stratum	6	0.5287	0.11	
Period/Day/Animal stratum				
Fearfulness	1	18.7384	22.84	<1%
Residual	71	58.2411		
Total	80	78.0032		

Table 9d.2 Effect of fearfulness on time taken to negotiate the HGMS stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	0.0641	0.14	
Period/Day stratum	6	1.4073	0.40	
Period/Day/Animal stratum				
Fearfulness	1	0.0995	0.17	68.0%
Residual	71	41.1793		
Total	80	42.7502		

Table 9d.3 Effect of fearfulness on time taken to negotiate the MSEA stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	7.2685	6.09	
Period/Day stratum	6	3.5781	0.78	
Period/Day/Animal stratum				
Fearfulness	1	0.0169	0.02	88.2%
Residual	71	54.3206		
Total	80	65.1841		

Table 9d.4 Effect of fearfulness on time taken to negotiate the Diversion stage

Variation Source	d.f.	sum squares	Variance ratio	Sig
Period stratum	2	0.5281	2.42	
Period/Day stratum	6	0.6558	0.29	
Period/Day/Animal stratum				
Fearfulness	1	4.4606	12.02	<1%
Residual	71	20.7745		
Total	80	26.0323		

CHAPTER 10

EFFECT OF FEEDING, FEARFULNESS AND AGE ON BEHAVIOUR AND MILKING CHARACTERISTICS OF COWS IN THE MILKING STALL OF AN AUTOMATIC MILKING SYSTEM

1 Introduction

Before the development of the automatic concentrate feeders the most practical method of feeding cows on an individual basis was during milking (Whipp 1992). Most prototype designs of automatic milking system have the facility to feed the cow concentrate while she is being milked (Artmann 1992, van der Linde and Lubberink 1992, Winter 1993, Allen et al. 1992).

Behavioural problems associated with feeding during conventional milking may include slow exiting, because the cows are busy licking the bowl or waiting for more food (Whipp 1992). Whipp (1992) also suggested that cows may be more restless when fed in the parlour because, when finished, they search for more food or try to steal their neighbour's, resulting in fighting, fidgeting and eliminatory behaviour. Feeding the cows in the parlour may also alter their stance, since the feeding stance may be different to the non-feeding stance. In order to attach the teat cups the robot must have clear access to all the teats. If one of the hind legs is placed forward of the other, this reduces the clearance that the robot has to work under the udder. In these circumstances the robot may collide with the back legs while finding a teat and an attachment will be compromised.

Other problems associated with feeding during milking might include concentrate dust build up around the parlour and vermin may be encouraged where food for human consumption is extracted and stored. Dust and vermin may be particular problems for automatic milking because the system relies on light beams to determine where the cow is, these can be blocked by a coating of concentrate dust. Mice could pose particular problems if, encouraged into the parlour by the concentrate, they chew through the electrical cabling that controls the milking stall.

In order to milk a cow successfully, the robot must be able to attach the teat-cups. This is best achieved when the cow is standing still. If the cow moves about in the stall the attachment rate may be compromised. Kicking may create problems if the teat cups are knocked off since re-attachment of individual teat cups may be more difficult than in conventional systems. Feeding the cows during the attachment process may keep them quieter by distracting them from the workings of the robot and the stall. Two other benefits of feeding cows in the milking stall, specific to automatic milking, are first that it may attract them into the system. Secondly, on entering the milking stall the food, at the head of the stall, may encourage the cows to mount a step or put their heads into a yoke, thereby moving to a desired position which may be dependant on the length of the cow.

Svennersten and Samuelsson (1993) showed that feeding cows during milking led to higher milk flow rates and shorter milking times. Svennersten et al. (1990) also showed a tendency, although not significant, for milk yield to rise when cows were fed in the parlour. These effects were only seen when both morning and afternoon milkings were combined. These phenomena are probably mediated through the hormone oxytocin which rises to facilitate let down but also rises in response to feeding. This cumulative effect leads to a more intense and longer oxytocin peak which allows more milk to be extracted from the udder (Svennersten et al. 1990).

Another factor that may affect how the cows behave in the milking stall is how fearful or bold they are. Fearful cows may be more `twitchy' during attachment whereas bold cows may be less nervous of the procedure. The procedure and results, for estimating fearfulness with the group of cows used here, have been presented and discussed in chapter 7. Old cows may also `fidget' more in the milking stall than young cows, if their hooves are sore due to clinical or subclinical lameness.

There are other factors which may affect the cow's behaviour in the milking stall of an automatic milking system. These would include whether or not the cow wants to be milked (see chapter 6), curiosity and unexpected stimuli. These might include system malfunctions, strangers entering the parlour or experimental staff walking through the parlour while the cow was being milked. Unexpected external noises, sights or smells may also affect the cow's behaviour.

The aim of this experiment was to study the reaction of the cows to being fed or not fed in the parlour, specifically at some measures of restlessness, to determine if feeding makes the cows more restless, as suggested by Whipp (1992). The behavioural measures included frequency of shuffling, kicking and eliminatory behaviour. Some milking parameters were also studied to try to replicate the results shown by Svennersten et al. (1990) and Svennersten and Samuelsson (1993) mentioned earlier. In addition, the effects of fearfulness and age were considered to see if fearful (because they are more frightened) or old cows (because they have sore feet) were more restless than bold or young cows.

This experiment was the third in a series of three reports (see also chapters 8 and 9) studying factors affecting attendance at, and behaviour in, the AMS.

2 Materials and Methods

2.1 Experimental Design

The experiment was designed in a 3X2 latin square design with two groups of seven cows, on two treatments (fed or not fed in the parlour) over three periods. Each period lasted eight days and during each period one group of cows was fed and the other was not. The design is shown in table 10.1.

Table 10.1 Experimental design

	Period 1	Period 2	Period 3
Group 1	Fed	Not fed	Fed
Group 2	Not fed	Fed	Not fed

2.2 The System

The system has been described in detail in chapter 2

2.3 General Method

The general method is the same as that described in chapter 8.

During this experiment certain precautions were taken to prevent eliciting behaviour other than that due to the treatments. During the experiment visitors were generally discouraged and were prohibited during the three recording days at the end of each period. The operators were also prohibited from making excessive noise or walking through the parlour when the cows were being milked. During attachment an operator crouched near the cow to rectify any system failures speedily. The farm staff were made aware of the sensitivity of the experiment and, although they were not prohibited from entering the shed (to service other animals), they made an effort to minimise the disturbance they caused.

2.4 Training

The training period has been described in chapter 8

2.5 Data Recording

The data recording was divided into two main areas; behavioural data and milking parameters. The behavioural data were recorded for both the attachment and milking phase. The attachment phase was defined as starting from the time the robot started to move until it returned to the home position after attachment. The milking phase then started and finished when the last teat cup was removed. The behavioural data were recorded manually. During attachment this was from beside the cow, and during milking from inside the control room. The milking parameters for each milking were recorded automatically onto the database of the management computer. For the analysis the data for the first milking of the day for each cow (AM) and the combined data for all milkings during the day (All) were recorded. Details of the data recorded are shown in the table below

Table 10.2 Behavioural and Milking Parameters Recorded

<u>Behavioural Parameters</u>:

Step- Any hesitation of more than approximately 5s in mounting the step was recorded

Leg position- Recorded as good or bad, a bad position was defined as the cow having one rear leg more than 10cm in front of the other, as measured from a grid marked on the stall floor

Shuffling- General weight shifting when the foot was lifted less than about 10cm off the ground. Individual foot movements were not recorded but bouts of shuffling were. A bout had to be preceded by a non-shuffling period of at about 15s to be defined as a new bout

Kicking- This was a determined leg movement that rose at least about 10cm off the ground and was a faster movement than shuffling.

Attachment Failures- How often the robot failed to attach the teat cup

Eliminatory Behaviour- Urination and defecation

Vocalising

<u>Milking Parameters:</u>

Yield (AM)- First milking of the day yield recorded for each quarter but summed for the analysis (l).

Milk out (AM)- First milking of the day time taken to milk out (s).

Flow rate (AM)- First milking of the day flow rate calculated by dividing the yield by the time taken to milk out (ml/s).

Yield (All)- Sum of all milkings throughout the day (l).

Milk out (All)- Average of all milkings of the day (s).

Flow rate (All)- Average of all milkings of the day (ml/s).

<u>2.6 The animals</u>

The individual cow data are shown in chapter 7.

2.7 Analysis

2.7.1 Behavioural data

The effect of feeding on shuffling was examined using analysis of variance. The average shuffling rate for each cow was calculated for each of the three periods. These data were normally distributed. The individual cows were nested within period in the analysis. The other behaviours were analysed using the Wilcoxon matched pairs test. Groups 1 and 2 were true replicates and were analysed as such. Within each group two comparisons could be made (since there were three periods) between periods 1 and 2 and periods 2 and 3; although these were not true replicates. The effect of age and fearfulness on behaviour in the milking stall were analysed using the Mann-Whitney U test. For these analyses all the data across the nine recording days were combined.

2.7.2 Milking characteristics

The effect of feeding on milking characteristics was measured using analysis of variance blocked by period, day and animal. Individual animals were nested within each of the three days in each period and days were nested within periods. The effect of fearfulness and age was analysed similarly except that, for age, the treatment structure was age and feeding or not feeding, while for the fearfulness analysis only fearfulness was used in the treatment structure (since all the bold cows belonged exclusively to group 2).

3 Results

3.1 Summary of Raw Data

A brief summary of the data is given in the table below. The attachment columns show data for the attachment process and the milking columns show data for the milking process, the treatments are shown in the second row. The number of milkings for the two treatments were different because the cows attended of their own volition.

Table 10.3 Data for the effect of feeding or not feeding in the milking stall on frequencies of occurrence of particular behaviour and milking characteristics

	Attachment		Milking	
	Fed	Not fed	Fed	Not Fed
Number of Milkings	165	152	165	152
Behavioural:				
Step hesitations (%)	0	0	0	0
Poor leg posn. (%)	17.0	18.4	9.9	12.5
Shuffles (per milking)	0.9	1.3	3.8	3.8
Kicks (%)	0.1	1.3	7.3	10.5
Ruminating (%)	0.1	12.5	1.2	19.7
Elimination (%)	0	0	0	0
Vocalising (%)	0	0	0	0
	Fed		Not Fed	s.e.d.
Milking:*				
Yield (AM)+ (l)	12.55		13.33	0.75
Milk out (AM) (s)	262.75		362.00	20.50
Flow rate (AM) (ml/s)	35.36		37.28	1.67
Yield (All)++ (l)	21.16		20.25	1.02
Milk out (All) (s)	810.50		732.50	43.25
Flow rate (All) (ml/s)	27.68		28.72	1.28

* Mean results derived from analysis of variance.
\+ Means from the morning milking only
\++ Means from all milkings combined

3.2 Behavioural Parameters

3.2.1 Effect of treatment on shuffling

The effect of feeding on the frequency of shuffling during attachment and milking was examined using analysis of variance. The data for the last three days of each period were summed and the average number of shuffles per milking was then calculated (since some cows had different frequencies of milking). The blocking structure was cows nested within periods. The treatment structure was fed or not fed in the parlour.

Cow 123 was removed from this analysis because she tended to scratch herself on the framework of the stall and consequently moved about in the stall more than she might. A summary of the analysis of variance is shown in table 10.4. The details of the analysis are shown in appendix 10a.

Table 10.4 Effect of feeding in the milking stall on the mean number of shuffles per milking for the attachment and milking phase

	Fed	Not Fed	s.e.d.	Sig.
Mean shuffles/attachment	6.7	3.4	2.07	5.3%
Mean shuffles/milking	1.95	0.98	0.48	12.2%

During attachment the cows tended to shuffle more when they were fed than when they were not, and this approached significance. During milking there was no such effect.

3.2.2 Effect of treatment on teat misses

There were no effects of feeding or not feeding on the frequency of teat misses for either group 1 or group 2 on either of the quasi-replicates ($p>5\%$, Wilcoxon matched pairs test, one-way, $n=7$). The frequencies for each analysis are shown in table 10.5.

Table 10.5 Effect of feeding or not feeding in the parlour on the frequency of a teat miss during an attachment for a whole udder, for each group in each pseudo replicate (significance derived from Wilcoxon matched pairs test)

		Fed	Not fed	Significance
Group 1	Periods 1 and 2	70%	22%	n.s.
	Periods 2 and 3	44%	57%	n.s.
Group 2	Periods 1 and 2	54%	22%	n.s.
	Periods 2 and 3	44%	43%	n.s.

3.2.3 Effect of treatment on leg position

The frequencies for each analysis are shown in table 10.6

Table 10.6 Effect of feeding or not feeding in the milking stall on frequency of poor leg positions at the start of attachment, for each group in each pseudo replicate (significance derived from Wilcoxon matched pairs test)

		Fed	Not fed	Significance
Group 1	Periods 1 and 2	23%	17%	n.s.
	Periods 2 and 3	12%	30%	n.s.
Group 2	Periods 1 and 2	11%	17%	n.s.
	Periods 2 and 3	9%	12%	n.s.

Feeding had no effect on the frequency of poor leg positions at the start of attachment ($p>5\%$, Wilcoxon matched pairs test, one-way, $n=7$). The average probability of a poor leg position was 17% at the start of attachment and 10% at the start of milking. This difference was significant ($p<1\%$, Wilcoxon matched pairs test, one-way, $n=14$, data averaged across the three periods for each cow). At the start of attachment in period 3 the cows had significantly improved their leg positions compared to the start of attachment in period 1 ($p<1\%$, Wilcoxon matched pairs test, one-way, $n=14$). The probability of a poor leg position at the start of attachment in period 1 was 26% compared to 10% in period 3.

3.2.4 Effect of feeding or not feeding on stepping onto the platform

There were no recorded hesitations by the cows in mounting the step.

3.2.5 Effect of feeding or not feeding on eliminatory behaviour

There was no recorded eliminatory behaviour during attachment or milking.

3.2.6 Effect of feeding or not feeding on number of kicks

There were only 30 reported kicks out of 317 milkings over the 9 recording days of the three periods. 13 of these were by cow 1107 and five by cows 0081, 1067 and 1118, cows 2050 and 335 were never observed kicking.

3.3 Effect of feeding in the parlour on milking parameters

The effect of the treatments on yield, flow rate and time taken to milk out were examined using analysis of variance. The data was blocked by individual animals nested within each day, which were nested within each period. The treatment structure was fed or not fed in the milking stall. In the first part of this analysis all the data for all the milking were used (All). In the second analysis only the data for the first milking of the day were used (AM). The analysis of variance can be seen in detail in appendix 10b.

3.3.1 Average milking parameters for each treatment for all milkings (All)

The data averages are shown in table 10.7 for the three milking parameters.

Table 10.7 Effect of parlour feeding on milking parameters for all milkings (All)

	Fed	Not fed	s.e.d	Significance
Yield (L)	21.16	20.25	1.02	n.s.
Flow rate (ml/s)	27.60	28.72	1.28	n.s.
Milk out time (s)	810.50	732.50	43.25	7.4%

There was no significant effects of the treatments. The milk out differences however, approached significance. Each cow spent an average of 13.5 minutes being milked per day on the fed treatment but only 12.2 minutes per day being milked when they were not fed.

3.3.2 Effect of treatment on milking parameters for the first milking of the day (AM)

These data were analysed in the same way as for the last analysis with the data blocked by period, day and animal with feed or no feed as the treatment. The data were derived from the first milking of the morning for each cow. Some cows did not have stored data for this milking because of system errors (seven missed data points out of a total data set of 126). While the interval between milkings will have been different for each cow the minimum interval will have been nine hours, since the cows did not have access to the system during the night between 21:00 and 06:00, but probably substantially more. The analysis is shown in detail in appendix 10c and in table 10.8

Table 10.8 Effect of parlour feeding on milking parameters for the first morning milking (AM)

	Fed	Not fed	s.e.d	Significance
Yield (L)	12.55	13.33	0.75	n.s.
Flow rate (ml/s)	35.36	37.28	1.67	n.s.
Milk out time (s)	362.75	362.00	20.50	n.s.

There was no significant effect of the treatments on any of the milking parameters.

3.4 Effect of fearfulness on the cows' behaviour and milking parameters

3.4.1 Effect of fearfulness on behaviour in the milking stall

The effects of fearfulness on shuffling are shown in table 10.9 for the attachment and milking phase.

Table 10.9 Effect of fearfulness on shuffling during attachment and milking, average number of shuffles per milking for bold and fearful cows over the three periods (significance derived from Mann-Whitney U test)

	Fearful	Bold	Sig.
Attachment	0.9	1.6	n.s.
Milking	4.1	3.6	n.s.

There was no significant difference in the level of shuffling for the bold or fearful cows for either the attachment or milking phase ($p>5\%$, Mann-Whitney U test, one-way, $n_1=4$, $n_2=5$).

The effect of fearfulness on leg position is shown in table 10.10.

Table 10.10 Effect of fearfulness on poor leg positions at the start of attachment and milking, average chance of an attachment failure for bold and fearful cows over the three periods (significance derived from Mann-Whitney U test)

	Fearful	Bold	Sig.
Attachment	19%	18%	n.s.
Milking	6%	13%	n.s.

There was no effect of fearfulness on the probability of a poor leg position ($p>5\%$, Mann-Whitney U test, one-way, $n_1=4$, $n_2=5$)

There was not enough recorded behaviour to assess the effects of fearfulness on any other behavioural criteria reliably.

3.4.2 Effect of fearfulness on milking characteristics

This was analysed using analysis of variance. The data were blocked by period and day, with day nested within period. The effect of feeding in the parlour could not be incorporated since the cows were not evenly distributed across the groups 1 and 2. The main results of this are shown in table 10.11 while more details of the analysis are shown in appendix 10d.

Table 10.11 Effect of fearfulness on milking parameters for all milkings

	Fearful	Bold	s.e.d	Significance
Yield (L)	20.46	21.12	1.31	n.s.
Flow rate (ml/s)	25.32	27.80	1.50	n.s.
Milk out time (s)	835.50	783.00	54.40	n.s.

There was no significant effect of fearfulness on any milking characteristics.

3.5 Effect of age on behavioural and milking parameters

3.5.1 Effect of age on behaviour in the milking stall

The data for the amount of shuffling during attachment and milking are shown in table 10.12.

Table 10.12 Effect of age on shuffling during attachment and milking, average number of shuffles per milking for bold and fearful cows over the three periods (significance derived from Mann-Whitney U test)

	Young	Old	Sig.
Attachment	0.7	0.9	n.s
Milking	1.78	4.7	<5%

During milking the old cows shuffled more than the young cows ($p<5\%$, Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$). There was no such effect during attachment

($p>5\%$, Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$).

The effect of age on poor leg positions is shown in table 10.13.

Table 10.13 Effect of age on poor leg positions at the start of attachment and milking, average chance of an attachment failure for bold and fearful cows over the three periods (significance derived from Mann-Whitney U test)

	Young	Old	Sig.
Attachment	13%	23%	n.s.
Milking	11%	8%	n.s.

There were no effects of age on poor leg positions at the start of attachment or milking ($p>5\%$, Mann-Whitney U test, one-way, $n_1=3$, $n_2=3$).

3.5.2 Effect of age on milking parameters

The effect of age on the three milking parameters is shown in table 10.14. The data were analysed using an analysis of variance blocked by period and day, with day nested within period. The treatment structure was parlour feeding and age. More details of the analysis can be seen in appendix 10e.

Table 10.14 Effect of age on milking parameters for all milkings

	Young	Old	s.e.d	Significance
Yield (L)	26.02	23.11	1.46	5.2%
Flow rate (ml/s)	31.36	28.64	2.18	n.s.
milk out time (s)	836.00	867.25	62.95	n.s.

This table suggests that there was little effect of age on any of the three milking parameters, apart from a trend for the older cows to yield less.

4 Discussion

4.1 Behaviour in Stall

The results showed that feeding cows in the milking stall tended to increase the level of shuffling while the teat cups were being attached. This agrees with Whipp's (1992) hypothesis that cows may be more restless when fed while being milked. This activity may have been generated by the act of the cows eating the concentrate nuts out of the feeder or because, when they had finished their food, they may have been more restless. When not fed the cows did not appear to look for food and were often seen ruminating (32% of all milkings).

The cows significantly improved their leg positions during the attachment process and during the course of the experiment, suggesting that they were accommodating to the action of the robot. If they exhibited a poor leg position at the start of attachment, the robot often collided with the `forward' leg causing the cow to move, generally to a more accessible stance.

There was no effect of feeding or not feeding on the frequency of kicking, eliminatory behaviour or vocalising, indeed the low level of all of these behaviours suggests that the cows were not adversely affected by the milking process. The frequency of kicking, a potentially problematic behaviour in the AMS, since it can damage the robot or the cow, seemed unrelated to feeding but appeared strongly related to individual cows. Cow 1107 accounted for nearly half of all recorded incidents.

These data suggest that none of the behavioural measures were improved by feeding, indeed feeding cows while they were being milked tended to increase the level of shuffling.

4.2 Milking parameters

There appeared to be little effect of feeding concentrate in the parlour on the time taken to milk out, flow rate or total yield, either in the first milking of the day or for all the milkings during the day combined. This is in contradiction to the results of Svennersten and Samuelsson (1993) who suggested that there would be shorter milk out times and higher flow rates when the cows were fed. The results of their experiment are shown in table 10.15.

Table 10.15 Published milking parameters (Svennersten and Samuelsson 1993)

	Fed (s.d.)	Not Fed (s.d.)
Yield (l)	16.77 (0.16)	16.07 (0.16)
Milk out (s)	505 (10.2)	529 (10.2)
Flow rate (ml/s)	31.66 (0.66)	35 (0.66)

These results are different to the result obtained for the morning milking in this experiment. The yields in their experiment were approximately 3.5l more, while the milk out times were substantially higher (approximately 150s) and flow rates were marginally lower. There could be a number of reasons for the lack of any significant effect including 1) the cows were of a different breed (Swedish red and whites vs Holstein/Friesians). 2) The milking plant will have been different, as was the vacuum level (50kpa compared to our 45kpa), or 3) the lack of significance may have been due to the substantially higher variation within our experiment.

The milking parameter data from our experiment suggests that there were no benefits of feeding cows while they are being milked on any of the milking parameters mentioned here.

4.3 Effect of Fearfulness

There were no effects of fearfulness on any of the behavioural measures or milking characteristics. Therefore, the hypothesis that fearful cows may be more `twitchy' while being milked is not supported.

4.4 Effect of age

The only effect of age on the behavioural parameters was in the amount of shuffling during milking. This was higher for the older cows; possibly they found the floor more uncomfortable than the younger cows (as a result of their hooves being in poorer condition). The milking parameters suggest that there was no effect of age, including the total time spent being milked, which suggests that the increase in shuffling was not due to the cows spending longer in the milking stall.

5 Conclusion

This experiment showed no benefits to feeding cows in the parlour. Feeding the cows was associated with increased levels of shuffling during attachment. There appeared to be no effect of feeding the cows on kicking, mounting the step, leg position or elimination; neither was there any benefit for the successful teat cup attachment rate. There was no significant effect on any of the milking parameters of feeding.

Fearful cows exhibited behavioural and milking characteristics no different from bold cows.

Old cows tended to shuffle more than young cows (but not significantly). There were no other effects.

Appendix 10

In the following tables 'Fnf' refers to the treatment feeding or not feeding in the parlour. * indicates an interaction, and / indicates a block nested within the preceding block

Appendix 10a Analysis of variance for effect of feeding on shuffling

Table 10a.1 Analysis of variance for the effects of feeding on shuffling during attachment

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum				
Fnf	1	2.602	5.35	
Residual	1	0.486	0.22	
Period/animal stratum				
Fnf	1	9.067	4.03	5.3%
residual	35	76.435		
TOTAL	38	88.574		

Table 10a.2 Analysis of variance for the effects of feeding on shuffling during milking

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum				
Fnf	1	69.55	33.91	
Residual	1	2.05	0.05	
Period/animal stratum				
Fnf	1	105.07	2.52	12.2%
residual	35	1416.75		
TOTAL	38	1593.34		

Appendix 10b Analysis of variance for milking parameters for all milkings

Table 10b.1 Analysis of variance for the effects of the treatment on yield for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	6.702	1.52	
Period/day stratum	6	1.321	0.68	
Period/day/animal stratum				
Fnf	1	2.624	0.80	37.3%
residual	116	3.747		
TOTAL	125	4.027		

Table 10b.2 Analysis of variance for the effects of the treatment on the milk out time for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	2.424	3.53	
Period/day stratum	6	2.063	0.36	
Period/day/animal stratum				
Fnf	1	3.065	3.25	7.4%
residual	116	1.093		
TOTAL	125	1.169		

Table 10b.3 Analysis of variance for the effects of the treatment on flow rate for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	3.783	1.77	
Period/day stratum	6	6.394	0.29	
Period/day/animal stratum				
Fnf	1	2.405	0.66	41.7%
residual	116	420.837		
TOTAL	125	433.418		

Appendix 10c Effect of treatment on milking parameters at the first daily milking

Table 10c.1 Analysis of variance for the effects of the treatment on yield at the first milking

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	1.604	0.24	
Period/day stratum	6	2.00	1.86	
Period/day/event stratum				
Fnf	1	1.897	1.06	30.6%
residual	109	1.955		
TOTAL	118	2.178		

Table 10c.2 Analysis of variance for the effects of the treatment on the milk out time for the first milking

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	163023	0.73	
Period/day stratum	6	671877	0.53	
Period/day/event stratum				
Fnf	1	337	0.00	96.8%
residual	109	23087806		
TOTAL	118	23878940		

Table 10c.3 Analysis of variance for the effects of the treatment on flow rate for the first milking

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	0.028	0.00	
Period/day stratum	6	37.083	1.13	
Period/day/event stratum				
Fnf	1	7.253	1.32	25.3%
residual	109	598.10		
TOTAL	118	640.16		

Appendix 10d Effect of fearfulness on milking characteristics for all milkings

Table 10d.1 Analysis of variance for the effects of fearfulness on yield for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	7.035	1.84	
Period/day stratum	6	1.144	0.62	
Period/day/event stratum				
Fearfulness	1	7.861	0.26	61.5%
Residual	62	1.911		
TOTAL	71	2.104		

Table 10d.2 Analysis of variance for the effects of fearfulness on milk out for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	714049	4.23	
Period/day stratum	6	506012	0.40	
Period/day/event stratum				
Fearfulness	1	197349	0.93	34%
Residual	62	13211827		
TOTAL	71	14629237		

Table 10d.3 Analysis of variance for the effects of fearfulness on flow rate for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	3.659	0.56	
Period/day stratum	6	19.496	1.29	
Period/day/event stratum				
Fearful	1	6.807	2.71	10.5%
Residual	62	156.028		
TOTAL	71	185.991		

Appendix 10e Effect of age on milking characteristics for all milkings

Table 10e.1 Analysis of variance for the effects of age on yield for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	11.225	5.12	
Period/day stratum	6	2.965	0.17	
Period/day/event stratum				
Fnf	1	2.104	0.07	78.6%
Age	1	1.128	3.99	5.2%
Fnf*Age	1	2.771	0.00	97.5%
Residual	42	1.186		
TOTAL	53	1.363		

Table 10e.2 Analysis of variance for the effects of age on flow rate for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	2.426	6.27	
Period/day stratum	6	5.558	0.24	
Period/day/event stratum				
Fnf	1	3.227	0.82	37.1%
Age	1	6.143	1.56	21.9%
Fnf*Age	1	0.340	0.09	77.0%
Residual	42	165.513		
TOTAL	53	183.207		

Table 10e.3 Analysis of variance for the effects of the fearfulness on milk out for all milkings

Variation Source	d.f.	sum squares	Variance ratio	Significance
Period stratum	2	239441	89.35	
Period/day stratum	6	221616	0.17	
Period/day/event stratum				
Fnf	1	284418	1.35	25.3%
Age	1	51516	0.24	62.4%
Fnf*Age	1	30637	0.14	70.5%
Residual	42	8876549		
TOTAL	53	9704177		

CHAPTER 11

DAIRY COWS' CHOICE TO ENTER AN AUTOMATIC MILKING SYSTEM WITH AND WITHOUT A CONCENTRATE REWARD

1 Introduction

Chapter 6 showed that some cows chose to be milked when given the choice between being milked or not in a Y-maze, although there was a high level of individual variation. When early lactation cows were given the choice of being milked or being fed concentrate they always chose to be fed even if they had not been milked for longer than 12 hours. This and the individual variation suggests that motivation to be milked is weak.

The cows had to work significantly less in choosing to be milked in the Y-maze than they would in an AMS. The cows were made to enter the holding stall of the Y-maze and it then required only a small amount of work by them to choose the milking spur. In the AMS the cows had to decide to be milked spontaneously, break away from whatever behaviour they were engaged in, separate from the herd and enter the AMS. This may therefore reduce the level of motivation to be milked exhibited.

The questions asked in this chapter were 1) do cows exhibit any motivation to be milked in the AMS? 2) Is this dependant on stage of lactation? And 3) how does attendance change when the cows are given a reward of concentrate in the AMS? This experiment also reexamined the relationship between attendance rates and age, rank and fearfulness to replicate the results shown in chapter 8, where old and low ranking cows attended the milking stall less often than younger and higher ranking cows.

This experiment also aimed to reexamine the effect of feeding concentrate in the exit area of the AMS on the time taken to enter and leave the parlour. The results of experiment 2 in chapter 9 suggested that there were no effects of feeding in the parlour or the type of food in the exit area on the time taken to move from the ID stall to the holding gate. The same was largely true for the next stage as well; from the holding gate to the milking stall. Here however, there was a significant interaction between feeding concentrate in the parlour and the type of food provided in the exit area, feeding forage in the exit area and not feeding concentrate in the milking stall increased the time taken to move through this stage. There appeared to be no effect on the time taken to leave the milking stall of the exit area feed type and feeding or not feeding in the parlour. In this experiment the design was simpler so the effect of feeding or not feeding concentrate in the exit area on the time taken to enter and leave the milking stall could be considered. Also all cows were routed through the milking stall regardless of whether they need to be milked or not (if they did not need to be milked they were let straight through the milking stall). This was to ameliorate the effect of cows loitering in the ID stall when they are directed down the alternative route (milking or diverting) to the one which they wanted to use (Ketalaar-de-Lauwere 1992, Winter 1993).

The final aspect of this experiment concerned the potential for the frequency of attendance to be manipulated for high and low yielding cows by the provision of different amounts of concentrate. In this experiment the low yielding cows received less concentrate than the higher yielding cows to determine if attendance rate could be modified by this method. This may be a useful tool to generate high attendance rates for high yielding cows and low attendance rates for low yielding cows.

2 Materials and Method

2.1 General Method

The AMS has been described in chapter 2. In this experiment the system was operated manually. The gates were controlled from inside the control room using a control panel and the teat-cups were attached manually.

The cows came through the milking stall whenever they visited; no cows were diverted at any time. If a cow visited the AMS and had not been milked within the last four hours she was milked. The cow's teats were cleaned in the milking stall and the teat cups attached. The teat cups were removed from each teat manually when each quarter had milked-out, and her teats dipped in teat dip. The milking stall exit door was then opened, allowing the cow to walk from the milking stall into the exit area. If the cow had been milked in the last four hours, she was let straight through the milking stall into the exit area without being stopped. The cows were not fed in the milking stall.

The system was available to the cows between 04:00 and 22:30, but between 13:30 and 14:00 the system was closed for cleaning.

Any cow who failed to attend the AMS during the day was milked after the system had been closed to voluntary traffic (22:30). Between 22:30 and 04:00 all the gates between the bedded area and the exit area (via the milking stall) were opened allowing the cows free access to the exit area.

2.2 Experimental design and data recording

The experiment comprised two eight-day periods, the first involved giving the cows no feed reward in the AMS. In the second period the cows were fed concentrate in the exit area of the milking stall via the two automatic concentrate feeders described in chapter 2. Cows in early lactation received 4kg of concentrate per day, while cows in late lactation cows received only 2kg per day. The concentrate was rationed on a variable interval schedule where the cow could receive as much concentrate as had accrued since her last visit, as a proportion of her 24h ration. The cows were also fed the complete ration described in chapter 2 *ad lib.* in the bedded area.

The time at which each cow entered, whether she was milked or not milked and the time taken to enter and exit the milking stall were all recorded manually.

2.3 Experimental Animals

The cows were selected from the dairy herd at Cheseridge Farm, belonging to the Institute for Animal Health, Compton. They were selected for being in good health, of quiet disposition and with good hooves. Twelve cows were selected ranging in age, with six in early lactation and six in late lactation. Details of the animals are given in tables 11.1 and 11.2 (where DIM refers to days in milk).

Table 11.1 Details of the animals used

Cow	Yield (l)	Parity	DIM (d)	Fearful score	Rank	Group
139	26.5	3	189	3	2	High
562	23.2	4	130	4	7	High
902	29.0	7	138	5	8	High
1205	27.8	2	154	8	6	High
9566	33.0	4	144	3	4	High
9592	25.5	4	152	8	1	High
216	11.5	3	270	6	10	Low
331	13.8	2	283	3	3	Low
519	14.5	4	269	4	12	Low
880	15.5	5	288	3	5	Low
1105	13.2	2	273	6	9	Low
2181	13.3	1	271	3	11	Low

11.2 Average yield, parity and DIM for each group

Group	Yield l, (s.d.)	Parity	Fearful score	Rank	DIM d, (s.d)
High	27.52 (3.36)	4.00	5.17	4.67	151 (20.56)
Low	13.63 (1.35)	2.83	4.00	8.33	275 (7.89)

The high yielding group were of significantly higher rank than the low yielding group ($p<5\%$, Mann-Whitney U Test, two-way, $n_1=6$, $n_2=6$). There were no other significant relationships

2.4 Age, Rank and fearfulness scoring

Rank and fearfulness were determined using the method described in chapter 7. In the rank determination there was only one confirmed circular relationship and that was between cows 1105 and 880. The cows' ages, ranks and fearfulness scores are shown in table 11.1. Six cows were classed as old; 562, 902, 9566, 9592, 519, and 880 and four as young; 1205, 331, 1105 and 2181. Five cows were classed as bold; 139, 9566, 331, 880 and 2181 and four as fearful; 1205, 9592, 216 and 1105.

2.5 Training

For ten days prior to the start of the experiment the cows were trained. The first three days involved running the cows through the system without milking them. For the remaining seven days the cows were batch milked twice per day to accustom them to the milking process.

2.6 Analysis

The effect of feeding or not feeding in the AMS on attendance was analysed using the Wilcoxon Matched Pairs test. Differences in attendance between the high and the low yielders were assessed using the Mann-Whitney U test. The effects of feeding or not feeding in the exit area on the times taken to enter and exit the milking stall were analysed using analysis of variance from the data for the last three days of each period, blocked by cow. The data were transformed by taking their natural logarithms to normalise their distribution. The effects of age and fearfulness on attendance were assessed using the Mann-Whitney U test. The effect of rank on attendance was analysed using the Spearman's rank test.

3 Results

3.1 Attendance with no food reward

The number of times that each animal chose to be milked on each day are shown in table 11.3.

Table 11.3 Number of milking choices for each cow for each day with no food reward in the AMS

Cow	Day:1	2	3	4	5	6	7	8	Total
139 (High)	1	0	1	2	2	1	1	1	9
562	1	1	1	1	1	1	1	1	8
902	0	0	0	0	0	0	0	0	0
1205	1	0	0	1	0	1	0	1	4
9566	3	4	3	6	4	5	5	3	33
9592	1	0	1	1	0	0	0	1	4
Total (High)	7	5	6	11	7	8	7	7	58
216 (Low)	0	0	0	0	0	0	0	0	0
331	0	0	0	0	0	0	0	0	0
519	0	0	0	0	0	0	0	0	0
880	0	0	1	3	1	0	3	2	10
1105	0	0	0	2	0	0	1	0	3
2181	2	1	2	5	3	4	7	5	29
Total (Low)	2	1	3	10	4	4	11	7	42

The majority of cows failed to attend the AMS at a frequency that would be acceptable for automatic milking (i.e. more than twice per day). Eight cows did attend the system voluntarily but some at a very low frequency. Two cows, 9566 and 2181, accounted for 62% of all milkings. Three cows in the low yielding group and one in the high yielding group failed to attend voluntarily. There was no significant difference between the total number of milkings for the early and late lactation cows ($p>5\%$, Mann-Whitney U test, one-way, $n_1=6$, $n_2=6$). Figure 11.1 plots the cumulative attendance for the early and late lactation cows (summed for each day) when they were not fed in the parlour.

During this part of the experiment 902 and 519 both contracted mastitis and both recovered by the end of the period.

3.2 Attendance with concentrate reward

The number of attendances for each cow for each day when the cows were fed concentrate in the exit area of the milking stall are shown in table 11.4

Table 11.4 Number of milking choices for each cow for each day with a food reward in the AMS

Cow	Day:1	2	3	4	5	6	7	8	Total
139 (High)	3	1	4	4	3	3	4	5	27
562	6	3	5	7	5	5	7	6	44
902	1	0	0	0	0	1	-	-	2
1205	4	2	4	2	2	3	2	1	20
9566	6	4	4	7	7	7	6	7	48
9592	5	2	9	7	6	7	9	8	53
Total (high)	25	12	26	27	23	26	28	27	194
216 (Low)	1	0	0	0	0	0	0	0	1
331	0	1	0	0	0	0	0	0	1
519	0	0	0	0	0	0	0	0	0
880	4	2	4	2	1	1	0	0	14
1105	1	1	1	2	3	5	0	2	15
2181	9	7	7	5	3	6	5	3	45
Total (Low)	15	11	12	9	7	12	5	5	76

All the early lactation cows except one, 902, entered the AMS on average more than twice per day. However all the late lactation cows except one, 2181, attended the AMS on average less than twice per day. The high yielding cows attended the AMS significantly more often that the low yielders ($p<1\%$, Mann-Whitney U test, one-way, $n_1=6$, $n_2=6$). Figure 11.2 plots the cumulative attendance for the high and low yielding groups when they were fed in the AMS.

The high yielders attended the AMS significantly more when they were fed than when they were not fed ($p<5\%$, Wilcoxon matched pairs test, one-way, $n=6$). The low yielders did not ($p>5\%$, Wilcoxon matched pairs test, one-way, $n=6$)

During this part of the experiment 902 contracted mastitis again and was eventually withdrawn from the experiment for the final two days.

3.3 Effect of age, rank and fearfulness on attendance rates

There was no effect of age on attendance rates ($p>5\%$, Mann-Whitney U test, one-way, $n_1=6$, $n_2=4$). The spearman's rank correlation coefficients between rank and

Figure 11.1: Cumulative choices to be milked by the high and low yielding groups when not fed in the AMS

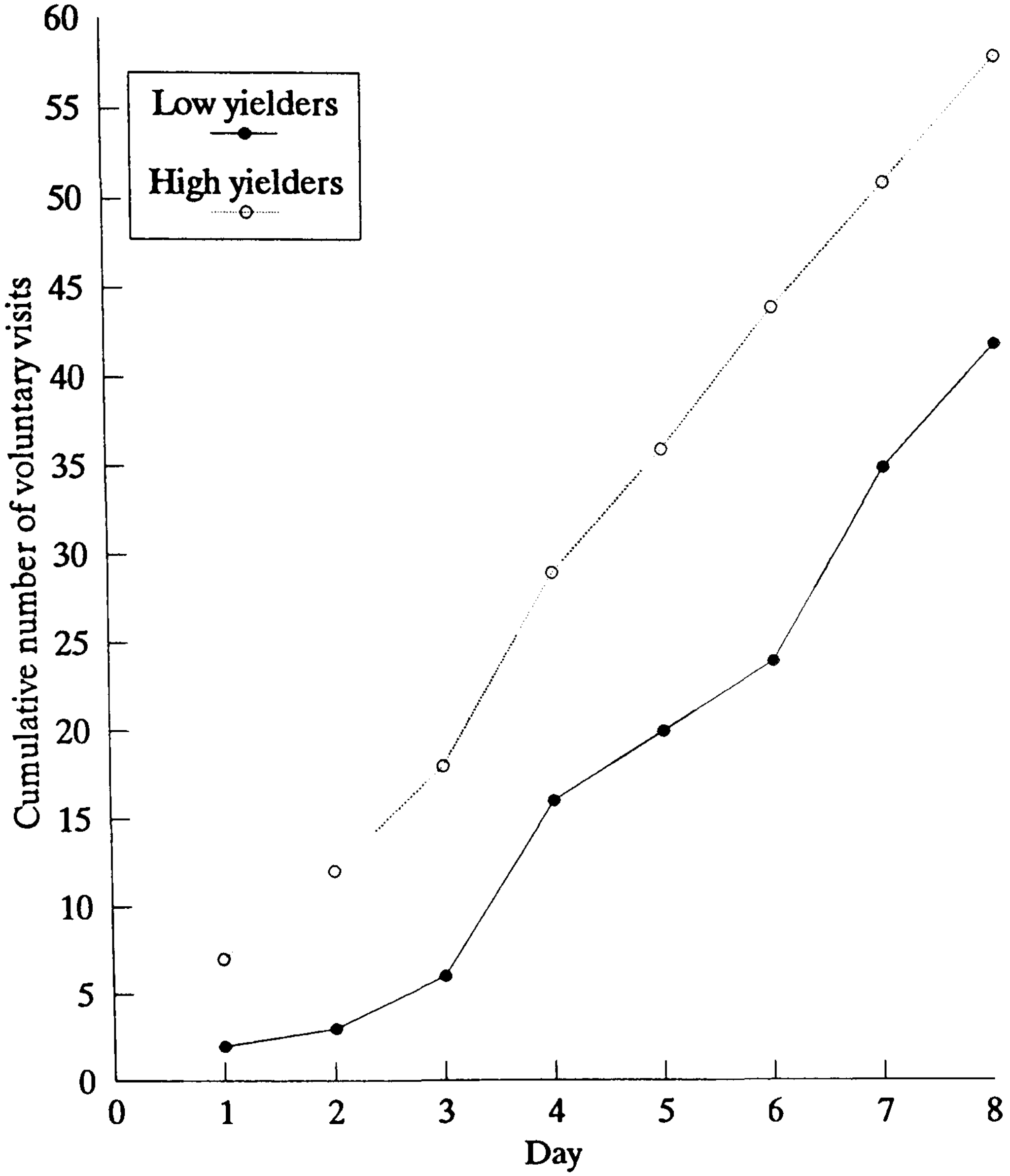
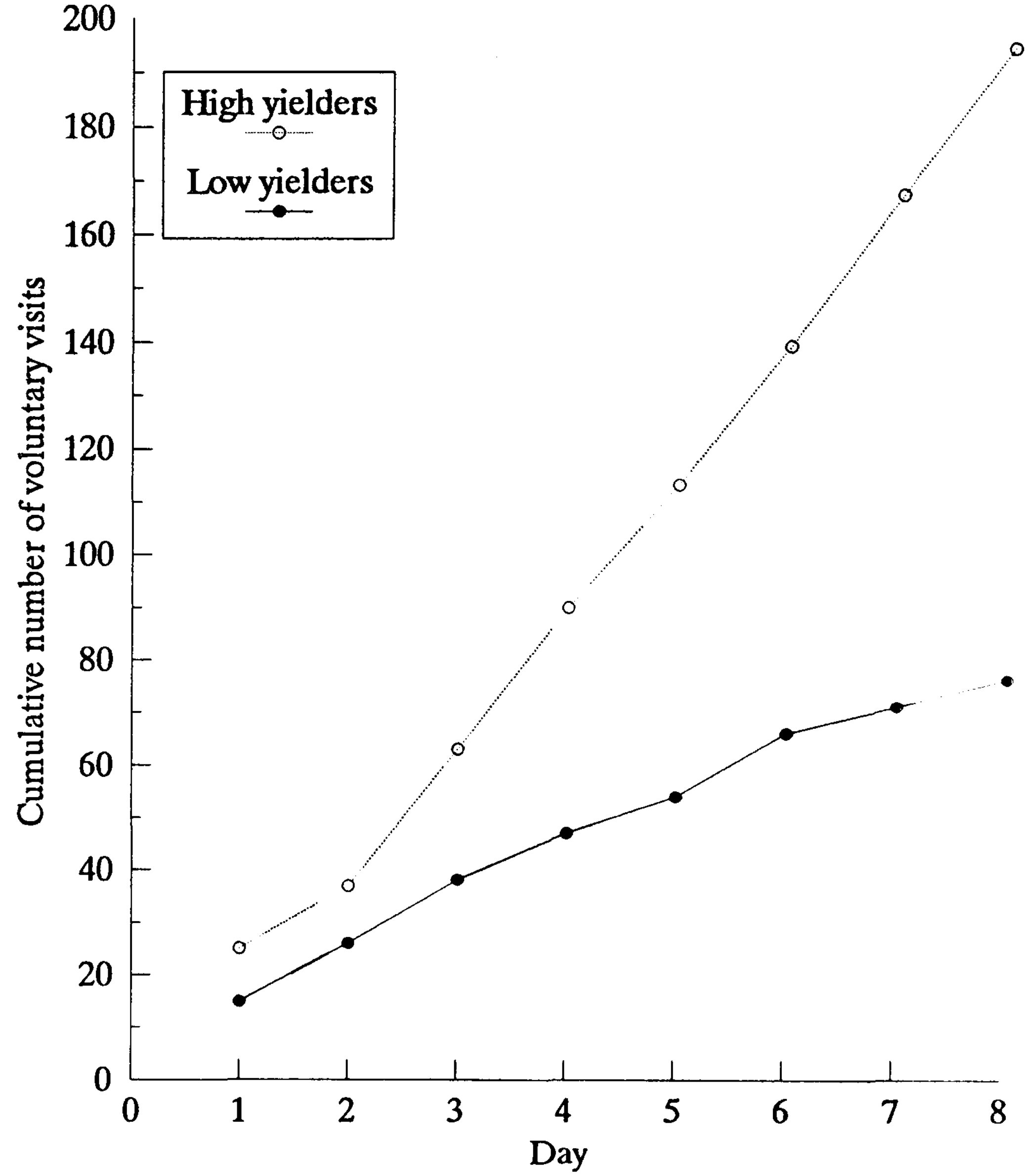


Figure 11.2: Cumulative number of visits by the high and low yielding groups when fed concentrate in the AMS



attendance rate were -0.27 when the cows were fed and -0.44 when they were not fed, neither was significant ($p>5\%$, Spearman's rank, $n=12$).

When not fed the bold cows visited the system more often than the fearful cows ($p<5\%$, Mann-Whitney U Test, one-way, $n_1=5$, $n_2=4$). This was not so when they were fed ($p>5\%$, Mann-Whitney U Test, one-way, $n_1=5$, $n_2=4$).

3.4 Effect of feeding on entry and exit times

This effect was examined using analysis of variance with the entry and exit times taken from the last three days of each part of the experiment for all voluntary milkings. Some cows failed to attend voluntarily in either part and so could not be used in the analysis. These cows were 902, from the high yielding group, and 216, 331 and 519 from the low yielding group. The analysis was blocked by individual cow. A summary of the analysis is given in table 11.7, details of the analysis can be found in appendix 11.1.

Table 11.7 Effect of feeding concentrate in the exit area of the milking stall on time taken to enter and exit the parlour. Values expressed as their natural logarithms to allow comparison with the s.e.ds. Bracketed figures indicate back transformed means in seconds.

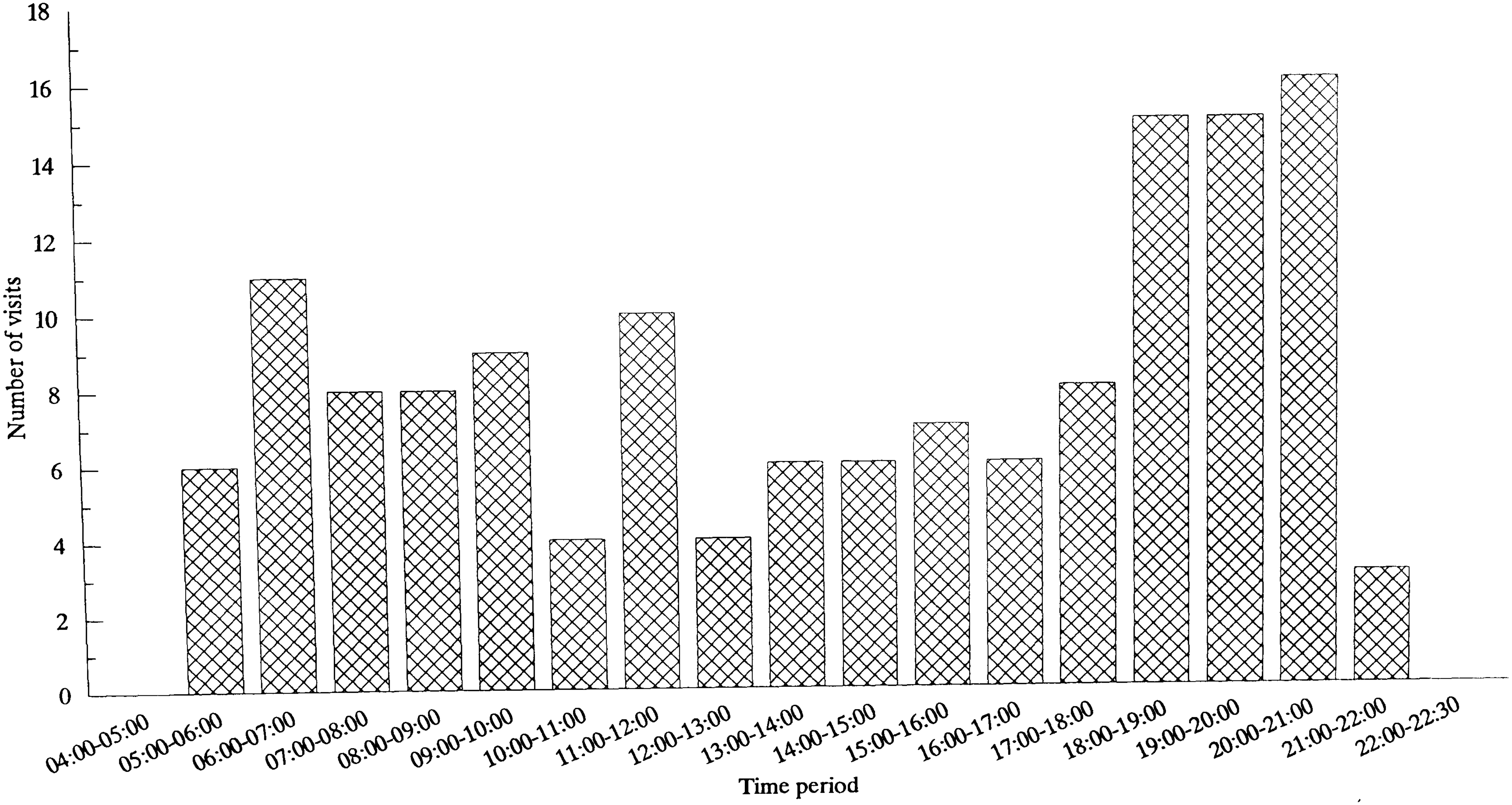
	Fed (s)	Not fed (s)	s.e.d.	Significance
Entry	4.05 (57.4)	4.75 (115.2)	0.21	$p<1\%$
Exit	4.30 (73.6)	4.75 (115.3)	0.22	$p<1\%$

Feeding the cows concentrate in the exit area of the milking stall highly significantly reduced the time taken by the cows to enter and exit the parlour.

3.5 Pattern of attendance

The pattern of attendance is shown in figure 11.3 were the average attendance rates by the cows over the last three days of each part of the experiment are plotted for each hour during the day. The cows were consistent in their attendance during the day. For the seventeen hours between 05:00 and 22:00 the cows hourly attendance rate did not differ significantly from the average hourly attendance rate (Chi-square test, $p>5\%$ d.f.$=16$). The cows did not visit the system before 05:00 or after 22:00.

Figure 11.3: Frequency of attendance during the experimental day (sum of last three days of each part for all cows)



4 Discussion

4.1 Effect of feeding concentrate on attendance

The high yielding cows made significantly more visits to the AMS when fed than when not fed. This suggests that the motivation to visit the AMS is higher when the cows are fed than when they are not. This result may have been due to the cows habituating to the system, since the experimental design was confounded with time. The low yielders did not significantly increase their level of attendance when fed which suggests that the 2kg of concentrate was insufficient to increase their motivation to visit the system.

The cows did still make some visits to the system even when not fed, but there was little difference in the frequency of attendance between the high and low yielding cows. The low level of attendance does indicate some motivation to be milked but in agreement with the Y-maze experiments (chapter 6), it appears to be weak and variable between cows.

Two cows attended the system frequently even when not fed. In the case of 2181 this may have been to escape the attentions of higher ranking cows; she was a small heifer and was often seen being bullied by other cows. Cows 9566 was not a low ranking cow and there is no obvious reason why she attended as often as she did. She was however, an extremely `friendly' cow who often solicited attention from the farm staff and the AMS operators, therefore she may have been entering the system in an attempt to solicit attention.

This experiment showed that the value of the reward can affect how often the cows attend the system, since the low yielders, fed only 2kg/day, attended significantly less often than the high yielders, fed 4kg/day. The level of the food reward may have affected this as well as the difference in hunger that the high and low yielders may have felt, the high yielders probably being hungrier than the low yielders since they are producing more milk. Three cows in the low yielding group largely failed to visit the system voluntarily even when fed. This may be because the forage far exceeded their nutritional requirements and they may not have been hungry. One cow from the high yielding group also failed to attend the system when fed (902). When she was forced into the system, she often yielded in excess of 25l, but always appeared nervous. She was an old cow, with a large udder, who took a long time to milk out and had a history of mastitis.

This experiment showed that motivation to be milked cannot generate adequate attendance to the AMS. Regulating the level of concentrate fed may be a method by which attendance can be modified, for example, between high and low yielding cows. This may useful since the yield gains for milking a high yielding cow frequently are probably higher the gains from milking a low yielding cow frequently. If the capacity of the system to milk cows is limited (e.g. by time) then it may be preferable to milk the high yielding cow more often than the low yielding cow.

4.2 Effect of age, fearfulness and rank on attendance

There was no effect of age on the rate of attendance, in contrast to the results shown in chapter 8. Fearful cows visited the system significantly less than bold cows but not when they were fed. Presumably, when they were fed the motivation to enter the system was stronger than their fear of the system. Rank did not appear to affect attendance whether the cows were fed or not, although the effects of rank were confounded within the high and low yielding groups, the low yielding group being of significantly lower rank than the high yielding cows. The correlation coefficients for both periods 1 and 2 suggest that the data trends were in the same direction as the data shown in chapter 8.

4.3 Effect of feeding on time taken to move through the system.

The times taken by the cows to leave the milking stall were similar to those found in the first part of chapter 9 in that feeding the cows concentrate in the exit area significantly reduced the time taken to exit. The entry time was also significantly reduced when the cows were fed concentrate in the exit area, suggesting that concentrate in the exit area can accelerate the cows' passage through the whole of the system and not just in leaving the milking stall. This result was probably enhanced by the decision to route all the cows through the system, preventing them loitering because they wanted to use an alternative route to the one specified by the system.

4.4 Pattern of attendance

The cows seemed to attend consistently through the day which agrees with the results shown in chapter 8 for this sort of treatment. However the cows seemed to increase their attendance rates during the evening which may be a function of their crepuscularity. The cows entered the system mostly between 05:00 and 22:00 which suggests that an AMS in a commercial setting or future experimental trials need not operate outside of these times.

5 Conclusions

Feeding the cows in the AMS considerably increased the attendance rates of the high yielders, and there seemed to be a difference in the rate of attendance depending on feeding level. This may provide a mechanism of differentially regulating the attendance rates of the cows. Feeding the cows in the exit area significantly improved the entry and exit times. The cows were not motivated to enter the system between 22:30 and 05:00. Rank did not appear to affect attendance rates. However, fearful cows attended less often than bold cows when not fed.

There is some evidence for a motivation to be milked, however there is no indication that stage of lactation affects this.

Appendix 11

In the tables below 'Fnf' refers to the treatment feeding or not feeding in the parlour. / Indicates a block nested within the preceding block

Table 11a Effect of feeding or not feeding on time taken to enter the parlour

Variation Source	d.f.	Sum Squares	Variance ratio	Significance
Cow stratum				
Fnf	1	80957	3.36	
Residual	6	144704	12.19	
Cow/event stratum				
Fnf	1	73894	37.36	<1%
Residual	131	259114		
TOTAL	139	558669		

Table 11b Effect of feeding or not feeding on time taken to exit the parlour

Variation Source	d.f.	Sum Squares	Variance ratio	Significance
Cow stratum				
Fnf	1	187096	7.23	
Residual	6	155372	9.83	
Cow/units stratum				
Fnf	1	38882	14.76	<1%
Residual	136	358292		
TOTAL	144	739641		

CHAPTER 12

GENERAL DISCUSSION

The aim of this chapter is to draw together the conclusions from the experimental chapters and suggest how they relate to the concept of a voluntary automatic milking system. This chapter starts with a discussion of the methods used to study preferences. This is followed by a discussion on why cows may visit the AMS and how automatic milking may affect dairy cow welfare. The discussion then becomes more specific, considering the various behavioural challenges facing the implementation of voluntary automatic milking systems, and how aspects of the system may be designed based on knowledge of the cow's behaviour. This chapter concludes with some suggestions for the direction of future research involving dairy cow behaviour and automatic milking, and a summary of the research findings.

1 Preference tests and signalling

One problem of using Y-mazes to study motivation is that the animal may be exhibiting a preference for a particular spur irrespective of the treatment it contains. For example one spur may be darker or warmer than the other. Equally cows may exhibit some `handedness' in that they have a natural tendency to turn either left or right. This is thought to be a particular problem when animals have to choose between weakly motivating or similarly matched alternatives (Grandin et al. 1994), since the motivation to use a particular spur becomes significant compared with the motivation to choose one treatment. The tendency for cows to choose a particular spur was repeatedly exhibited at various times in the experiments reported in chapters 3 and 5. One way to ameliorate this effect may be to swop randomly the treatments between the spurs. However, a clear indication of which spur contains which treatment needs to be given to the cows, and the cows have to be trained to associate that signal with the treatment. Chapters 3, 4 and 5 of this thesis explored the practicality of training cows to associate a randomly located food reward in a Y-maze indicated by abstract visual signals.

Chapter 3 showed that dairy cows did not reliably show signs of associating an abstract visual signal with food, randomly located down either spur in the Y-maze. The cows did appear to associate simple visual signals which were closely associated with the reward. For example they appeared to associate a single bucket, or the colour of a bucket, with food, but largely failed to associate a red or yellow lit spur with food.

Using a novel food preference test (chapter 4), four foods were found which the cows exhibited a greater preference for than other foods. These foods were then used in a new series of experiments (chapter 5) as the rewards. The aim of this was to increase the value of the reward since it was felt that low reward value may have prevented the cows from associating, or showing signs of associating, the signal with the reward in chapter 3. The cows however, continued to show similar levels of association as they had in chapter 3.

Using visual signals to indicate the position of treatments in a Y-maze are therefore unlikely to be viable unless a more efficient method of training can be found. Dairy cows probably possess the ability to learn these associations. Breland and Breland (1966) described some experiments where cows were trained to perform tasks which appear far more complicated than those detailed here. Kilgour (1987) reported that dairy cows are as intelligent as dogs, who are generally regarded as being highly trainable. Some reasons for the lack of significant results described in chapters 3 and 5 may include a short training time, low stimulus strength, or an unwillingness by the cows to respond to a reward that may have been weakly reinforcing because it was too little or unpalatable.

Having largely failed to train cows to find food in the Y-maze using visual signals, the alternative was to place one treatment repeatedly down the same spur for half the experiment and then down the other spur for the second half. This protocol was still able to detect a preference for a particular spur, but not until quite far into the experiment. It may also have increased the preference for a particular spur, since the cows may initially choose a spur for the treatment it contains, but with time and repeated usage they may eventually choose that spur out of habit, even when the treatment is moved into the other spur. This protocol was used to assess the motivation to be milked in early and late lactation cows, and the relative motivation to receive $^1/_3$ kg of concentrate or be milked. Some cows did find one or other spur more attractive than the treatments, but only when given the simple choice between being milked or not. When the cows were given the choice to be fed or milked they showed no preferences for a particular spur but always chose the food spur, suggesting that motivation to eat concentrate is stronger than the motivation to use a particular spur.

In the light of these experiments it seems necessary that in any preference tests, using Y-mazes, where the treatments are only mildly or similarly motivating, some account must be taken of the tendency of dairy cows to choose a particular spur out of habit and not for the treatment it contains.

The food preference test detailed in chapter 4 gave repeatable results quickly. This sort of approach could be used where the relative preferences for particular foods are required. The tests showed that the cows had similar food preferences with minor individual differences. There was also some degree of dynamism in their preferences with one food becoming increasingly preferred at the expense of another.

2 Principal motivations involved in voluntary automatic milking

2.1 Motivation to be milked

This thesis has shown that some, but not all, cows show a motivation to be milked as suggested by Phillips (1993) and Rathore (1982). As Winter (1993) speculated, however, it is not an important factor in affecting the cows' attendance at the AMS.

These experiments showed that the weak motivation to be milked was not necessarily due to the discomfort of a large, heavy and full udder but could be due to another motivation, since the cows often chose to be milked every three and a half hours, at which interval they would have had little milk in their udders (by inference since the amount of milk in the udder was not measured). There was little evidence of early lactation cows being more motivated to be milked than late lactation cows. These data do not support Trivers' theory (1974) and other experimental data (Blass and Teicher 1980, Boe 1993) which suggest declining investment by parents in their offspring with increasing age. This may have been because the cows did not associate milking with suckling, and were gaining another reward from the process; perhaps let down itself was positively rewarding. Alternatively these cows may have chosen to be milked out of habit since they had been milked twice per day for most of their productive lives.

When cows were given access to the AMS with no food rewards, the attendance rate was poor for both high and low yielders alike (1.21 visits/cow/day and 0.88 visits/cow/day respectively). The high yielders did not volunteer to be milked significantly more frequently than the low yielders. There was also a high degree of individual variation in the results, two cows out of twelve attended very frequently (average 3.88 visits/cow/day) and four did not attend at all. These data show that there is some motivation to be milked exhibited in the AMS, but that this is lower than what might have been expected based on the evidence from the Y-maze. The four cows who never attended the AMS suggested that for some cows, milking in the AMS held no attraction and may be aversive. One possible reason for the disparity between the results from the Y-maze and the AMS may have been that in the Y-maze the 'cost' of choosing the milking option was less than the cost of choosing to be milked in the AMS. This is because in the Y-maze the cows were already standing-up, having been disturbed from whatever behaviour they were engaged in, and only had to choose to go left or right in the Y-maze decision area to be milked. In the AMS the cost of choosing to be milked was higher; the cows had to disengage from whatever behaviour they were pursuing, separate themselves from the herd and walk into the AMS. What this experiment did show was that cows did not necessarily choose to be milked, even if they had not been milked for 24 hrs and their udders appeared very distended. This again supports the suggestion that cows will not necessarily volunteer to be milked because of any discomfort they may feel from a distended udder.

Form these experiments it can be concluded that motivation to be milked cannot be used as a reliable motivator to attract cows to an automatic milking system.

2.2 Motivation to feed

In the Y-maze when high yielding cows were given the choice between being fed $^1/_3$ kg of concentrate or being milked, the cows invariably chose to be fed. This phenomenon was not restricted to the Y-maze. In the AMS when high yielding cows were fed nothing, the mean attendance was 1.2 visits/cow/day; however, when they were fed concentrate, attendance increased to a mean of 4.5 visits/cow/day. The high yielders, fed four kg of concentrate per day in the AMS, attended significantly more often than the low yielders fed only two kg per day. When neither group was fed there was no significant difference in the attendance rates of the two groups. This suggests that feeding different levels of concentrate generated a differential level of motivation to use the AMS between the high and low yielders.

When the cows were fed forage in the exit area (and concentrate in the bedded area) they attended more frequently than when they were fed concentrate in the exit area and forage in the bedded area (6.0 vs. 4.1 visits/cow/day). The number of milkings was slightly less when they were fed concentrate in the exit area (and forage in the bedded area) (2.6 vs. 2.4 milkings/cow/day). This difference in attendance may have been because the cows *needed* to eat forage since this is how they received most of their nutrients. When concentrate was fed in the exit area, and forage in the bedded area, the cows may have attended the AMS because they *wanted* to, for reasons other than the need to find nutrients and probably because of the taste of the concentrate. In this experiment the forage supplied the low yielders with all the nutrients they required and most of the high yielders' requirements. Attendance may have been higher if the forage was less nutritious and fed in the bedded area, with concentrate fed in the exit area, since the cows may have felt more of a *need* to eat concentrate to balance the shortfall of nutrients derived from the forage.

It would be naive to expect that the only two motivations affecting attendance to the AMS are motivation to be milked and to be fed. Other motivations likely to attract cows to the AMS might include using the AMS as a refuge to avoid bullying, to solicit attention, or out of curiosity or boredom. Motivations for cows to avoid the system might include the one-way races, neophobia, fearfulness, fear of isolation and aversion to being milked. Of these fears one of the most important may be fear of isolation which has been shown to be stressful to cattle (Hopster and Blokhuis 1994, Phillips 1993).

3 Dairy cow welfare and automatic milking

Automatic milking offers an opportunity to improve the welfare of dairy cows. One potential health advantage may include a reduced risk of mastitis due to more frequent removal of milk in the udder (Hillerton and Winter 1992), and reduced levels of lameness due to the udder being less distended (Webster 1995). Another benefit may come from an increased level of health monitoring. This is not to say that automatic health monitoring cannot be implemented in normal parlours, although the number of stalls needing equipping may make this less viable (Mottram 1992).

Behaviourally the benefits could be considerable. Probably the most important of these is that the cows can choose when they visit the system, since giving animals control over their environment has been linked with improved welfare (Broom and Johnson 1993, Maier and Seligman 1976). Some designs however, will give the cows more real choices than others. The cows may wait for shorter periods to be milked and presumably this will give them more time to eat and rest. Additionally, the system's operation will be constant from milking to milking, reducing the level of changes in the milking environment seen at present, for example by using relief milkers. The system will also never lose its temper.

Voluntary automatic milking may also reduce dairy cow welfare. One area of potential concern may be the lack of contact between the stock person and the cows. Milking is one means by which the cows and the stock person are kept in contact with one another. In modern parlours, however, the quality of this contact may be quite low, especially in large herringbone parlours where the stock person works behind the cows and may spend little time handling each cow. Clough (1983) reported that for a range of parlours and work routines, the time spent in contact with each cow per milking was less than one minute. Voluntary automatic milking systems may provide the stock person with more time, some of which could be spent engaged in quality contact with the cows. Therefore, conversely to the normal presumption, automatic milking could improve contact between the stock person and the cows.

One area where welfare could be most at risk is the generation of appropriate (i.e. frequent and well distributed) attendance. There is a range, from good to bad, of methods for luring cows to the AMS. This thesis looked at the provision of forage or concentrate in the AMS as a lure, and showed that concentrate can result in a similar number of milkings as can forage but the distribution of milkings was more even through the day. It was also shown that feeding forage in the exit area of the AMS results in modified forage eating and lying behaviour compared with feeding forage in the bedded area; the cows had fewer eating and lying bouts and ate and lay for less time in total. Both these behaviours have been highlighted as being potential problem areas for the high yielding dairy cow who may suffer hunger and fatigue simultaneously (Webster 1995) and, if nothing else, threaten the fourth of Webster's five freedoms (Webster 1995), that is, freedom to express normal behaviour. These results also corroborated the findings of two other researchers (Winter 1993, Ketelaar-de-Lauwere 1992). It is also suggested that feeding forage in the exit area may make the cows attend because they need to eat forage. Feeding concentrate in the exit area (and forage in the bedded area) may make cows attend because they want to eat the concentrate; probably because it tastes pleasant. Feeding concentrate however, may not be compatible with other feeding methods. For example cows may not be fed concentrate when they are also grazing or when they are being fed a totally mixed ration, therefore feeding additional concentrate may be an uneconomic option. There are however, two other options, either the concentrate lure could be accounted for as part of the cows' daily ration or another cheaper, but equally palatable, food could be fed to lure cows into the AMS.

The cow may have no more choices in her environment when she is fed forage in the exit area than when she is milked in a conventional system. In the AMS she has to attend to eat, in a conventional system she has to attend because the herds person dictates so.

It has been suggested that locating the cows' only source of water in the AMS could be used to encourage attendance (Artmann 1992). While this may not work operationally, since attendance will vary with the environmental temperature, the cow's milk yield (hence her water requirements) and the water content of the forage, it will also force cows to attend the system since they *need* to drink water. The effect of using water as the lure for attracting cows to the AMS needs careful consideration before it is implemented in commercial systems, to ensure that it does not unduly stress the cows.

Conceivably there are other possibilities for ensuring attendance, for example feeding poor quality or unpalatable forages which may necessitate the cows eating more often than they normally would. Overcrowding the living area may also improve attendance by increasing the general activity levels. These methods have never been suggested in the literature and should probably not be implemented in any automatic milking system that takes account of dairy cow welfare.

Finally, cows are unlikely to attend an AMS voluntarily and at an appropriate frequency when they are at grass, since the motivation to eat fresh grass is probably higher than the motivation to eat either forage or concentrate. Other problems with voluntary attendance and grazing include the distance from the field to the AMS (as the distance increases the cows should be less inclined to attend since the cost of attendance is increased) and the problems of roads crossing the farm (Collings 1995). The problems of social isolation for cows attending the AMS are also likely to be exacerbated.

If cows will not visit an AMS when grazing they will either have to be zero-grazed during the summer or milked at fixed times during the day after being collected from the fields. The Swedish animal husbandry legislation stipulates that cows must be allowed to graze for two or four hours per day (depending on location) in summer. It considers that systems which do not allow cows out for at least some of the year threaten dairy cow welfare (Gustaffsson and Magnusson 1994). In the UK grazing is often seen by farmers as a period of rest and recuperation for both the cows and the farmer from the rigours of winter housing and maintenance. The evident delight which cows exhibit when first let out to graze in spring suggests they too prefer this option. Zero grazing may therefore be seen by some as an unattractive option for automatic milking.

A possible alternative to zero grazing systems are autumn (or late summer) calving cows. During the summer the cows will be either yielding very little or be dry, therefore regular and frequent attendance to the AMS during this period becomes less important. As the cows calve they could be moved to housing near the AMS from where they would be more likely to attend.

4 Behavioural challenges facing implementation of voluntary automatic milking systems

4.1 Attendance

The general problems and main methods for encouraging attendance are given in the section above. However, there are also factors affecting individual cows which affect how often they attend. Low ranking and old cows attended less often than higher ranking and younger cows. This situation may be different in a larger group of cows but is unlikely to be improved. It may be that the farmer has to accept lower attendance rates for these cows and, if the situation became serious, cull the worst offenders. While culling would ameliorate the effects of age, it is unlikely to improve the effects of rank since removing current low ranking cows will generate future low ranking cows. It is likely that these sorts of culling decisions will need to be taken on an individual cow basis, since for some cows there is no yield advantage to frequent milking (Carruthers et al. 1993, Knight et al. 1994).

There also appeared to be some cows for whom the AMS seems aversive for no obvious reason and who never visited the system at all. Out of the 26 cows who have been allowed to visit the system voluntarily in these experiments, two cows never attended. Since these 26 cows probably represent a typical cross section of dairy cows, it is likely that this reflects what may be seen in commercial systems, i.e. 5-10% of the cows may never attend the system. If these reluctant cows do not learn to visit the system they would either have to be forcibly milked or culled. This estimate excludes the number of cows who may not be suitable for automatic milking for other reasons, for example teat positions, or cows who attend less frequently than desired. Comparisons with other trials are difficult since many were engineering trials which used cows who were previously selected to behave appropriately. It has been suggested, however, that only 85% of today's herd will be suitable for automatic milking (van der Linde and Lubberink 1992).

4.2 Movement through the system

In one experiment (experiment 2, chapter 9) there was little effect of feeding in the parlour or the type of food fed in the exit area on the time taken by the cows to move through parts of the AMS. The time taken to move through the diversion race however, was greater when the cows were fed forage as opposed to concentrate in the exit area. In another experiment (experiment 1, chapter 9) it was shown that the cows left the milking stall quicker when they were fed concentrate in the exit area than when they were not. This finding was supported by the experiment in chapter 11 where feeding concentrate in the exit area of the AMS encouraged cows into and out of the milking stall quicker than when they were fed nothing.

Therefore the conclusion of this appears to be that feeding concentrate, as opposed to forage, in the exit area of the AMS does not appear to increase the time that it takes the cows to move through the system, but that not feeding cows in the AMS does significantly increase their transit time.

One problem for the AMS is that it has places where cows are stopped. Stopping cows may result in them idling before they start moving again. Providing food rewards may help prevent cows idling.

The cows may not necessarily be attending the system solely to feed, however, so this method of luring the cows through the AMS with feed may not always work. A low ranking cow, for example, may stand in a particular place because her path is blocked by a high ranking cow, or because she does not want to move from a place of relative safety.

There are many engineering solutions to this problem. One of the most common is the mechanical `pusher'. Essentially this comprises an arm which pushes the cow through the system. The main problem with this method is that very fearful cows may be frightened by it, therefore affecting their attendance rate, while bold cows may soon learn that they can resist it or move just out of range. Another potential problem is that there must be some fail-safe mechanism which prevents the pusher from operating if a cow has fallen, is injured, chronically lame or even calving.

4.3 Kicking

Beyond failure to attend and blocking the system, some cows also engaged in other misbehaviour. Most serious of these is kicking (as defined in chapter 10) at the attachment robot, the consequences of which may include injury to the cow, damage to the system or an unsuccessful milking attempt. To prevent cows from kicking, and improve access to the udder, other design of AMS used tilting floor plates (van der Linde and Lubberink 1992, Winter 1993). This method however, only treats the symptoms and not the cause of the behaviour. In the author's opinion most kicks were a result of the robot colliding with one of the cows rear legs, the cow's inexperience of the system, or as the culmination of a chain of events often starting from a minor system malfunction. Ordolff (1987) found that touching cows' rear legs with a length of wood encouraged leg movements. It is unlikely that all causes of kicking can be prevented, and mechanical solutions for preventing kicking may only upset the cow further. The best solution, therefore, is to design a robot that, while minimising the potential to cause kicks, is able to withstand and recover from kicks (Ordolff 1987).

One of the benefits of the robot is that it does not fear injury when a cow kicks, and continues to behave according to its programming. A stock person in a similar situation may punish the cow by shouting at, hitting or fitting her with a kick bar, all of which may make the cow fearful of the milking process.

Feeding cows in the milking stall did not seem to affect the level of kicking, but kicking was strongly related to particular individuals.

5 Implications of behaviour for the design of the AMS

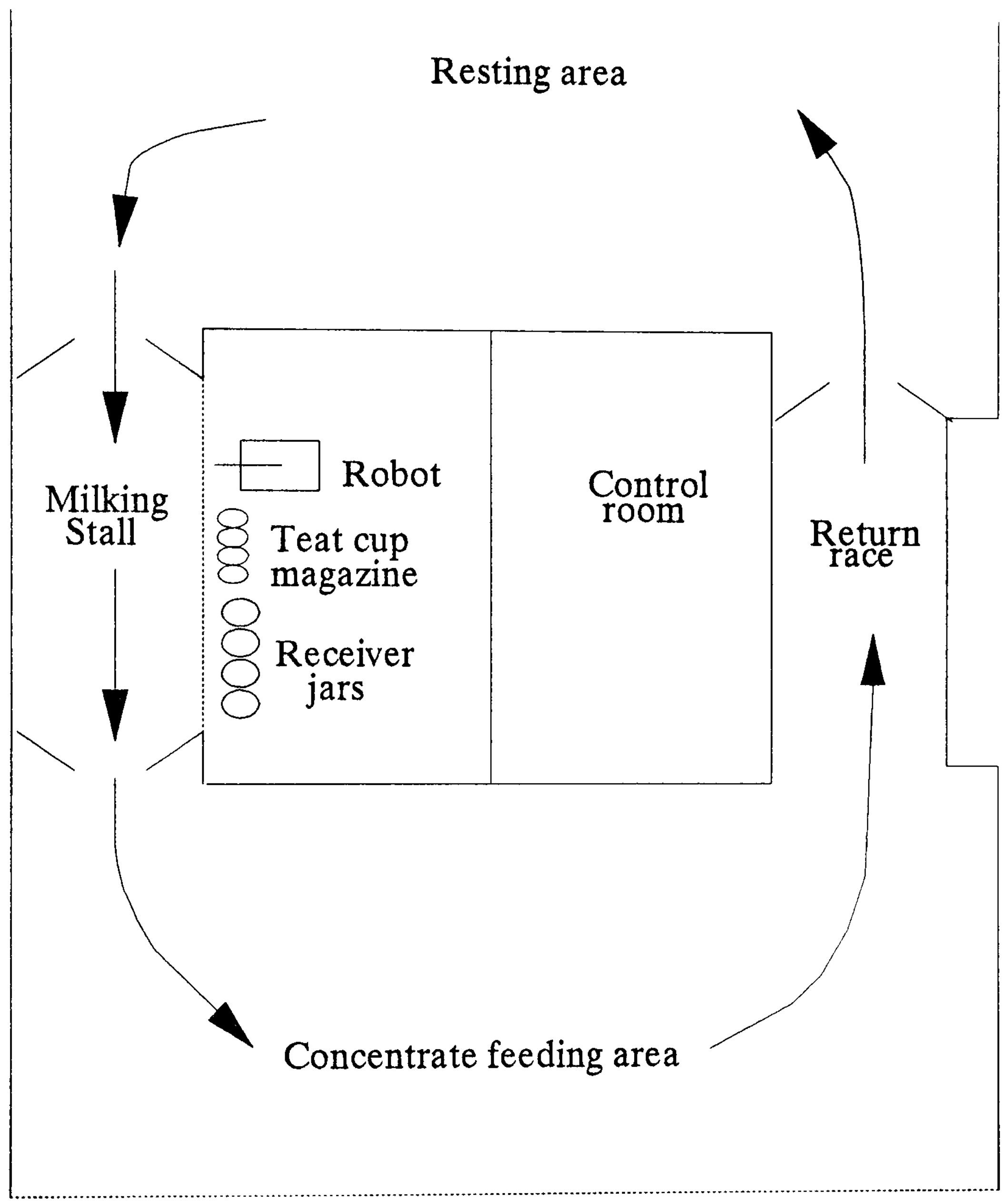
Cows must be fed in the AMS if they are to attend at an appropriate frequency. For the best attendance rates the cows should be fed forage in the exit area (and concentrate in the bedded area), there is no need to feed concentrate in the parlour. However, there are benefits to feeding concentrate in the exit area and forage in another area. Probably the most important is that the modifications to forage feeding and lying behaviour, associated with feeding forage in the exit area, are minimised. Another benefit of feeding concentrate in the exit area is that the quantity can be changed thereby altering the cow's motivation to eat and changing the frequency of attendance. For example late lactation cows could be attracted into the system at a lower rate than early lactation cows. Also when feeding concentrate in the exit area and forage in the bedded area, the cows' pattern of attendance was more evenly spread through the day, this should prevent the cows from queuing to enter the AMS, and allow a single milking stall to service more cows.

Cow controlled or passive selection lay outs, where the cows can reach the exit area direct from the bedded area, need further research to clarify whether they will work in the long term. Cows who are only motivated to use the system to eat may soon learn that they can avoid the system altogether by using an alternative route.

The best lay out is probably operator controlled (active selection). This has the AMS between the exit/feeding area and the bedded area, any cow wanting to use the exit area to feed would therefore have to pass through the AMS.

The elements of a possible lay out of an AMS are shown in figure 12.1. The rationale for this design of system is that if attendance can be kept low enough (but not too low), so that most of the visits result in milking, then the diversion system can be removed altogether. This would allow the cows to use the same route whenever they visited and may avoid the problems of cows standing in the ID stall anticipating entering the alternative race to the one that they are required to use. It may also remove the potential uncertainty associated with the cow being unable to predict which of the two different routes (into the milking parlour or into the diversion race) they will have to use (Winter 1993, Ketelaar-de-Lauwere 1992). This method may also prevent the cows having to be stopped at any point in the system unless they need to be milked, thereby

Figure 12.1: Alternative design for AMS



shortening the cows' transit time through the system.

In this design as the cow enters the milking stall the entry gate would close preventing another cow entering. If she were not being milked, she could be let straight through the system without being stopped. If she needed to be milked, the milking stall exit gate could close and she could be milked in the normal way.

This system would also be easily adapted to multiple stalls. This may increase the capacity of the system since a cow will not have to wait for another cow to finish being milked before she can enter the system. Multiple return races may improve the flow of the cows from the feeding area back into the resting area.

Improving the raceways may also help improve cow flow through the system. However there is a dilemma here, Grandin (1995) has suggested that the best raceways, in terms of optimal cow flow, are those that are featureless, evenly lit and have opaque sides. The AMS at present has none of these. However, an AMS with these features may increase the cow's sense of isolation. In this respect the design that best encourages attendance would be one that is open so a cow in the AMS can see and hear her herd mates. In the design shown in figure 12.1, an open design may be the best option since the cows may be more inclined to move into areas where they can see other cows.

6 Implications for future research

These investigations have clearly been small scale and short term, but still showed significant trends. The long term effects on cow behaviour of the AMS with larger cow numbers and heifers are unknown. It may be that the low attendance rates of some cows were because they were still unaccustomed to the system, or that their experiences of twice daily milking made it difficult for them to respond appropriately in the relatively short treatment periods. What may be of most benefit now in progressing this area of technology would be to conduct a long term (two or more years) large scale (30+ cows) trial, with an AMS that is both reliable and efficient. This trial could start by training heifers, with no experience of twice a day milking, to use the AMS initially to find food. As a heifer nears calving some of the milking operations could be built into her experience, for example the robot arm could start to articulate and the heifer could be held in the milking stall for a few minutes. When the heifer calves and has to be milked in the AMS she will probably be less disturbed by the milking process and more willing to use it effectively.

In addition the effect of automatic milking on the health of the dairy cows could be studied, for example the effect of frequent milking on lameness and mastitis.

7 Main Conclusions

The main conclusions from this thesis are as follows: 1) Dairy cows possess a weak motivation to be milked and this varies between cows. This motivation cannot be used to attract cows to an automatic milking system. 2) Cows will need to be fed if they are to visit an AMS at an appropriate frequency. 3) Feeding forage in the exit area of the AMS (such that the cows had to visit the AMS to access it) resulted in modified forage feeding and resting behaviour. 4) Feeding concentrate in the exit area resulted in a similar number of milkings as did feeding forage, but fewer total attendances. 5) Feeding concentrate in the parlour did not encourage additional attendance if the cows were also being fed in the exit area. 6) Feeding concentrate in the parlour did not modify the cow's behaviour during milking, apart from a trend to increase the level of shuffling.

Bibliography

Ainslie G., 1975. Specious reward: A behavioural theory of impulse and control. Psychological Bulletin., 82: 463-496.

Akam D.N. and Spencer S.B., 1992. Design and operation of milking machine components. In: Bramley A.J., Dodd F.H., Mein G.A. and Bramley J.A. (Editors), Machine milking and lactation. Insight books, Burlington USA, pp. 141-212.

Albright J.L., Gordon W.P., Black W.C., Dietrich J.P., Snyder W.W., Meadows, C.E.Etter R.W., 1966. Behavioural responses of cows to auditory training. Journal of Dairy Science 49: 104-106.

Albright J.L., Timmons M.B., 1984 Behaviour of dairy cows in free stall housing. Transactions of the American Society of Agricultural Engineers 27:1119-1126.

Albright J.L., Coe B.L., Colenbrander V.F., 1989a. Free stall acceptance and bovine laterality with various housing occupancy rates. Journal of Dairy Science 72: 98.

Albright J.L., Stouffer D.K., Coe B.L., 1989b. Cow comfort and preference in free stalls with reference to flooring and bedding. Journal of Dairy Science 72: 99.

Albright J.L., Cennamo A.R., Wisniewski E.W., 1992. Voluntary entrance into the milking parlour. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands, pp. 459-465.

Albright L.J., 1993. Feeding behaviour of dairy cattle. Journal of Dairy Science 76: 485-498.

Allen C.J. 1994. Personal communication.

Allen C.J., Mottram T.T., Frost A.R., Street M.J., Hall R.C., Spencer D.S., 1992. Field Trials of the Silsoe automatic milking system. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for Automatic Milking: Proceedings of the International Symposium on prospects for Automatic Milking. Pudoc Scientific Publishers, Wageningen,Netherlands, pp. 72-79.

Alsam H. and Wathes C.M., 1991a. Conjoint preferences of chicks for heat and light intensity. British Poultry Science 32: 899-916.

Alsam H. and Wathes C.M., 1991b. Thermal preferences of chicks brooded at different air temperatures. British Poultry Science 32: 917-927.

Anon., 1992. Collins soft back English dictionary. Harper Collins. Glasgow UK.

Anon., 1995. Advertisement. Dairy Farmer, July 1st: 67.

Appleby M.C., 1983. The probability of linearity in hierarchies. Animal Behaviour 31:

600-608.

Appleby M.C., Morae H.E., Paise B.E., 1983/4. The effect of light on the choice of nests by domestic hens. Applied Animal Ethology 11: 249-254.

Arave C.W. and Alright J.L., 1981. Cattle behaviour. Journal of Dairy Science 64: 1318-1329.

Arave C.W., Mickelsen C.H., Lamb R.C., Svejda A.J., Canfield R.V., 1975. Effects of dominance rank changes, age and body weight on plasma corticoids of mature dairy cattle. Journal of Dairy Research 60: 244-248.

Arave C.W., Temple W., Kilgour R., Matthews L.R., Walters J.L., 1983. Effect on heifer feeding preference of adding flavour or pelleting a dairy meal. Journal of Dairy Science 66: 107-112.

Arave C.W., Temple W., Leman J.V., Kilgour R., 1984. Discrimination ability and preference among milking machine functions by dairy cows. Applied Animal Behaviour Science 12: 313-325.

Arave C.W., Albright J.L., Armstrong D.V., Foster W.W., Larson L.L., 1992a. Effects of isolation of calves on growth, behaviour and first lactation milk yield of Holstein cows. Journal of Dairy Science 75: 3408-3415.

Arave C.W., Lamb R.C., Arambel M.J., Purcell D., Walters J.L., 1992b. Behaviour and maze learning ability of dairy calves as influenced by housing, sex and sire. Applied Animal Behaviour Science 33: 149-163.

Arnold G.W. and Dudzinski M.L., 1978. Ethology of free ranging domestic animals. Elsevier, Amsterdam, Netherlands.

Arnold G.W. and Grassia A., 1982/83. Social interactions amongst beef cows when competing for food. Applied Animal Ethology 9: 239-252.

Artmann R., 1992. Status, results and further development of an automatic milking system. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking. Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands.

Baile C.A. and Della-Fera M.A., 1981. Nature of hunger and satiety control systems in ruminants. Journal of Dairy Science 64: 1140-1152.

Bailey D.W., Rittenhouse L.R., Hart R.H., Richards R.W., 1974. Characteristics of spatial memory in cattle. Applied Animal Behaviour Science 23: 331-340.

Balch C.C., 1955. Sleep in ruminants. Nature 175: 940-941.

Baldwin B.A., 1992. Personal Communication.

Baldwin B.A., 1972. Operant conditioning techniques for the study of thermoregulatory behaviour in sheep. Journal of Physiology 226: 41p-42p.

Baldwin B.A., 1979. Operant studies on the behaviour of pigs and sheep in relation to the physical environment. Journal Agricultural Science 49: 1125-1134.

Baldwin B.A., 1981. Shape discrimination in sheep and calves. Animal Behaviour 29: 830-834.

Baldwin B.A. and Meese G.B., 1977. Sensory reinforcement and illumination preference in the domestic pig. Animal Behaviour 25: 497-507.

Baldwin B.A. and Start I.B., 1978. Methods for the study of illumination preferences in sheep and calves. Journal Physiology 284: 13p-14p.

Baron A., 1991. Avoidance and punishment. In: Iverson I.H., Lattal K.A. (Editors), Experimental analysis of behaviour: Part 1. Elsevier. London UK. pp. 173-212.

Bateson P., 1994. The dynamics of parent-offspring relationships in mammals. Trends in Ecology and Evolution 40: 399-402.

Beaudeau F., Ducrocq V., Fourichon C., Seegers H., 1995. Effect of disease on length of productive life of French Holstein dairy cows assessed by survival analysis. Journal of Dairy Science 78:103-117.

Beilharz R.G. and Mylrea, 1963. Social positions and movement orders of dairy heifers. Animal Behaviour 11: 529-533.

Beilharz R.G. and Mylrea P.J., 1963. Social position and behaviour of dairy heifers in yards. Animal Behaviour 11: 522-528.

Beilharz R.G. and Zeeb K., 1982. Social dominance in dairy cattle. Applied animal Ethology 8: 79-97.

Beilharz R.G., Butcher D.F., Freeman A.E., 1966. Social dominance and milk production in Holsteins. Journal of Dairy Science 49: 887-892.

Blass E.M. and Teicher M.H., 1980. Suckling. Science 210: 15-22.

Blodgett H.C., McCutchan K., Mathews R, 1949. Spatial learning in the Y-maze: The influence of direction, turn and food location. Journal of Experimental Psychology 39: 800-809.

Boe K., 1993. Maternal behaviour of lactating sows in a loose-housing system. Applied Animal Behaviour Science 35: 327-338.

Bouissou M.F. and Signoret J.P., 1971. Cattle behaviour under modern management techniques. Journal of the Farm Buildings Association 15: 25-27.

Breland K. and Breland M., 1966. Animal Behaviour. MacMillan, New York, USA

Bridges R., 1985. Prolactin stimulation of maternal behaviour in female rats. Science 227: 782-784.

Bridges R.S. and Millard W.J., 1988. Growth hormone is secreted by ectopic pituitary grafts and stimulates maternal behaviour in rats. Hormones and Behaviour 22: 194-206.

Broom D.M. and Johnson K.G., 1993. Stress and animal welfare. Chapman and Hall. London, UK

Brouns F. and Edwards S.A., 1994. Social rank and feeding behaviour of group-housed sows fed competitively or ad libitum. Applied Animal Behaviour Science 39: 225-235.

Bruckmaier R.M., Schams D., Blum J.W., 1993. Milk removal in familiar and unfamiliar surroundings: concentrations of oxytocin, prolactin, cortisol and beta-endorphins. Journal of Dairy Research 60: 449-456.

Bruckmaier R.M., Schams D., Blum J.W., 1994. Continuously elevated concentrations of oxytocin during milking are necessary for complete milk removal in dairy cows. Journal of Dairy Research 61: 323-334.

Carruthers V.R., Davis S.R., Bryant A.M., Henderson H.V., Morris C.A., Copeman P.J.A., 1993. Response of Jersey and Friesian cows to once a day milking and prediction of response based on udder characteristics and milk composition. Journal of Dairy Research 60: 1-11.

Clarkson MJ., Downham DY., Faull WB., Hughes JW., Manson FJ., Merritt JB., Murray RD., Russell WB., Sutherst JE., Ward WR, 1996. Incidence and prevalence of lameness in dairy cattle. Veterinary Record 138:563-567.

Clough P.A., 1983. Machine milking in cowsheds and milking parlours. In: Thiel C.C. and Dodd F.H. (Editors), Machine milking. NIRD/Hannah research institute: Technical bulletin 1. NIRD. Reading, UK. pp. 201-230.

Collings A., 1995. Look at robotic milkers. Farmers Weekly, 15th September: 72-73.

Collis K.A., 1976. An investigation of factors related to the dominance order of a herd of dairy cows of similar age and breed. Applied Animal Ethology 2: 167-173.

Collis K.A., 1980. The effect of an automatic feed dispenser on the behaviour of lactating dairy cows. Applied Animal Ethology 6: 139-147.

Cowie A.T., 1983. Anatomy and physiology of the udder. In: Thiel C.C. and Dodd F.H. (Editors), Machine milking. NIRD/Hannah research institute: Technical bulletin 1. NIRD. Reading, UK. pp. 156-178.

Cushnahan A. and Mayne C.S., 1995. Effects of ensilage of grass on performance and nutrient utilisation by dairy cattle. Animal Science 60: 337-345.

Dado R.G. and Allen M.S., 1994. Variation in the relationship among feeding, chewing and drinking variables for lactating dairy cows. Journal of Dairy Science 77:132-144.

Dawkins M., 1976. Towards an objective method of assessing welfare in domestic fowl. Applied Animal Ethology 2: 245-254.

Dawkins M.S., 1983. Battery hens name their price: Consumer demand theory and the measurement of ethological `needs'. Animal Behaviour 31: 1195-1205.

Dawkins M.S., 1990. From an animal's point of view: Motivation, fitness, and animal welfare. Behavioural and Brain Sciences 13: 1-61.

Dawkins R., 1989. The selfish gene. Oxford University Press. Oxford, UK.

Day M.L., Imakawa K., Clutter A.C., Wolfe P.L., Zalesky D.D., Neilson M.K., Kinder J.E., 1987. Suckling behaviour of calves with dams varying in milk production. Journal of Animal Science 65: 1207-1212.

Dellmeier G., Friend T., Gbur E., 1990. Effects of changing housing on open-field behaviour of calves. Applied Animal Behaviour Science 26: 215-230.

Dickson D.P., Barr G.R., Wieckert D.A., 1966. Social relationships of dairy cows in a feed lot. Behaviour 29: 195-203.

Dickson D.P., Barr G.R., Johnson L.P., Wieckert D.A., 1970. Social dominance and temperament of Holstein cows. Journal of Dairy Science 53: 904-907.

Dietrich J.P., Snyder W.W., Meadows C.E., Albright J.L., 1965. Rank order in dairy cows. American Zoologist 5: 713.

Dodd F.H. and Hall H.S., 1992. History and development. In: Bramley A.J., Dodd F.H., Mein G.A. and Bramley J.A. (Editors), Machine milking and lactation. Insight books. Burlington USA. pp. 1-36.

Draycott T., (1994): Personal communication.

Duncan I.J.H., 1977. Behavioural wisdom lost... Applied Animal Ethology 3: 193.

Duncan I.J.H., 1978. The interpretation of preference tests in animal behaviour. Applied Animal Ethology 4: 197-200.

Ely F. and Petersen W.E., 1941. Factors involved in the ejection of milk. Journal of Dairy Science 3: 211-223.

Entsu S., Dohi H., Yamada A., 1992. Visual acuity of cattle determined by the method of discrimination learning. Applied Animal Behaviour Science 34: 1-10.

Esslemont R.J., 1992. Counting the heavy cost of heifer losses. Farmers Weekly, 16th October: 40.

Farm Animal Welfare Council, 1993. Report on priorities for animal welfare research and development. MAFF, UK.

Federation of United Kingdom Milk Marketing Boards, 1993. Dairy facts and figures. Federation of United Kingdom Milk Marketing Boards, Thames Ditton, UK.

Fehrer E., 1951. Latent learning in the sophisticated rat. Journal of Experimental Psychology 42: 409-416.

Fiske J.C. and Potter G.D., 1979. Discrimination reversal learning in yearling horses. Journal of Animal Science 49: 583-588.

Fraser A.F., 1978 Tests in ethology. Applied Animal Ethology 4: 1-4.

Fraser A.F. and Broom D.M., 1990. Farm animal behaviour and welfare. Balliere Tindall, London UK.

Friend T.H., Gwazdanskas F.C., Polan C.E., 1979. changes in adrenal response from free stall competition. Journal of Dairy Science 62: 768-771.

Frost A.R., 1990. Robotic milking: A review. Robotica, 8: 311-318.

Frost A.R., Street M.J., Hall R.C., 1993. The development of a pneumatic robot for attaching a milking machine to a cow. Mechatronics, 3: 409-418.

Gellerman L.W., 1933. Chance orders of alternating stimuli in visual discrimination experiments. Journal of Genetic Psychology 51: 1672-1675.

Gibb M.J., Ivings W.E., Dhanoa M.S., Sutton J.D., 1992. Changes in body components of autumn-calving Holstein-Friesian cows over the first 29 weeks of lactation. Animal Science 55: 339-360.

Gilbert B.J.J. and Arave C.W., 1986. Ability of cattle to distinguish among different wavelengths of light. Journal of Dairy Science 69: 825-832.

Gleeson S., 1991 Response acquisition. In: Iverson I.H., Lattal K.A. (Editors),Experimental analysis of behaviour: Part 1. Elsevier. London UK. pp. 63-82.

Gomendio M., Cassinello J., Smith M.W., Bateson P., 1995. Maternal state affects intestinal changes of rat pups at weaning. Behavioural Ecology and Sociobiology 37: 71-80.

Gorewit R.C., Svennersten K., Butler W.R., Uvnas-Moberg K., 1992. Endocrine responses in cows milked by hand and machine. Journal of Dairy Science 75: 443-448.

Grambling G.E., Wieckert D.A., Jensen C.L., 1970. Learning ability in dairy calves. Journal of Dairy Science 53: 659.

Grandin T., 1995. Methods of reducing stress during handling and transport. British society of animal science winter meeting. Scarborough, UK. Paper 41.

Grandin T., Curtis S.E., Widowski T.M., Thurmon J.C., 1986. Electro-immobilization versus mechanical restraint in an avoid-avoid choice test for ewes. Journal of Animal Science 62: 1469-1480.

Grandin T., Odde K.G., Schutz D.N., Behrns L.M., 1994. The reluctance of cattle to change a learned choice may confound preference tests. Applied Animal Behaviour Science 39: 21-28.

Grindall R.J., Walton A.W., Hillerton J.E., 1991. Influence of milk flow rate and streak canal length on new intra-mammary infection in dairy cows. Journal of Dairy Science 58: 383-388.

Gustaffsson B. and Magnusson M. (1994): Dairy animal welfare: The case for Sweden. Dairy systems for the 21st century. Proceedings of the third international dairy housing conference. 2-5 February 1994, Orlando, Florida. American society of agricultural engineers.

Hacker R.R., Albright J.L., Taylor R.W., Hill D.L., 1969. Cow preferences for permanent bedding materials supported by different foundations in a free-stall slotted barn floor. Journal of Dairy Science 52: 918.

Harrison J.M., 1991. Stimulus control. In: Iverson I.H., Lattal K.A. (Editors), Experimental analysis of behaviour: Part 1. Elsevier. London UK. pp. 251-292.

Hays WL, 1994. Statistics. Harcourt Brace, London UK.

Head H.H., Kull R.C.J., Campos M.S., Bachman K.C., Wilcox C.J., Cline L.L., Hagen M.J., 1993. Milk yield, milk composition, and behaviour of Holstein cows in response to jet aircraft noise before milking. Journal of Dairy Science 76: 1558-1567.

Heffner R.S. and Heffner H.E., 1983. Hearing in large mammals: Horses (*Equus caballus*) and cattle (*Bos taurus*). Behavioural Neuroscience 97: 299-309.

Henke-Drenkard D.V., Gorewit R.C., Scott N.R., Sagi R., 1985. Milk production, health, behaviour, and endocrine responses of cows exposed to electrical current during milking. Journal of Dairy Science 68: 2694-2702.

Hill P., 1992. Bullies get their just deserts: Nothing! Dairy Farmer, November: 22-24.

Hillerton J.E. and Winter A., 1992. The effects of frequent milking on udder physiology and health. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers. Netherlands, pp. 201-212.

Hinch G.N., Thwaites C.J., Lynch J.J., Pearson A.J., 1982. Spatial relationships within a herd of young sterile bulls and steers. Applied Animal Ethology 8: 27-44.

Hinde R.A., 1959. Unitary drives. Animal Behaviour 7: 130-141.

Hooper P. and Richards S.A., 1991. Interaction of operant behaviour and autonomic thermoregulation in the domestic fowl. British Poultry Science 32: 929-938.

Hopster H. and Blokhuis H.J., 1994. Consistent individual stress responses of dairy cows during social isolation. Applied Animal Behaviour Science 40: 83-84.

Hopster H., Blokhuis H.J., Reenen C.G.van, 1992. Accuracy of a heart rate monitoring device for use with dairy cows. Journal of Animal Science 70: 166.

Hughes B.O., 1975. Spatial preference in the domestic hen. British Veterinary Journal 131: 560-564.

Hughes B.O., 1977a. Behavioural wisdom and preference tests. Applied Animal Ethology 3: 391-392.

Hughes B.O., 1977b. Selection of group size by individual laying hens. British Poultry Science 18: 9-18.

Hughes B.O., 1977c. Some implications of dominance hierarchies in intensive husbandry systems. Applied Animal Ethology 3: 199.

Hughes B.O. and Black A.J., 1973. The preference of domestic hens for different types of battery cage floor. British Poultry Science 14: 615-619.

Ipema A.H., Lippus A.C., Metz J.H.M., Rossing W., (Editors) 1992. Prospects for Automatic Milking: Proceedings of the International Symposium on Prospects for Automatic Milking. Pudoc Scientific Publish. Wageningen, Netherlands.

Janowitz H.D., Grossman M.I., 1949. Quoted in Manning 1979.

Jensen P., 1982/84. An analysis of agonistic interaction patterns in group-housed dry sows- Aggression regulation through an "avoidance order". Applied Animal Ethology 9: 47-61.

Jolley T., 1994. Personal communication.

Jongebreur A.A., 1992. Introduction. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 7-22.

Kempkens K. and Boxberger J., 1987. Locomotion of cattle in loose housing systems. In: Wierenga H.K. and Peterse D.J. (Editors), Cattle housing systems, lameness and behaviour. Martinus Nijhoff, London UK, pp. 107-118.

Kendrick K.M., 1990. Neural processing of visual recognition of individuals in sheep. In: Zayan D. and Dantzer R. (Editors), Social stress in domestic animals. Kluwer Academic Publishers, Netherlands, pp. 114-156.

Kennedy J.S., 1985. Displacement activities and post-inhibitory rebound. Animal Behaviour 33: 1375-1376.

Kenwright A.D and Forbes J.M., 1993. Relationships between social dominance and feeding behaviour in lactating heifers during periods of heavy competition. Animal Production 56: 457.

Ketelaar-de-Lauwere C.C., 1992. The use of a selection unit for automatic milking. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publish. Wageningen, Netherlands. pp. 270-279.

Key C. and MacIver R.M., 1980. The effects of maternal influences on sheep: Breed differences in grazing, resting and courtship behaviour. Applied Animal Ethology 6: 33-48.

Keys J.E., Smith L.W., Weinland B.T., 1976. Response of dairy cattle given a choice of free stall location and three bedding materials. Journal of Dairy Science 59: 1157-1167.

Kiley-Worthington M. and Savage P., 1978. Learning in dairy cattle using a device for the economical management of behaviour. Applied Animal Ethology 4: 119-124.

Kilgour R., 1975. The open field-test as an assessment of the temperament of dairy cows. Animal Behaviour 23: 615-624.

Kilgour R., 1981. Use of Hebb-Williams closed-field test to study the learning ability of Jersey cows. Animal Behaviour 29: 850-860.

Kilgour R. (1987): Quoted in Fraser and Broom 1990.

Kilgour R., Foster T.M., Temple W., Matthews L.R., Bremner K.J., 1991. Operant technology applied to solving farm animal problems. Applied Animal Behaviour Science 30: 141-166.

Klopfer F.D., Kilgour R., Matthews L.R., 1981. Paired comparison analysis of palatabilities of twenty foods to dairy cows. Proceedings of the New Zealand Society of Animal Production 41: 242-247.

Knight C.H. and Wilde C.J., 1993. Mammary cell changes during pregnancy and lactation. Livestock Production Science 35: 3-19.

Knight C.H., Hirst D., Dewhurst R.J., 1994. Milk accumulation in the bovine udder during the interval between milkings. Journal of Dairy Research 61: 167-177.

Kovalcik K. and Kovalcik M., 1986. Learning ability and memory testing in cattle of different ages. Applied Animal Behaviour Science 15: 27-29.

Kovalcikova M. and Kovalcik K., 1982/83. Relationships between parameters of the open field test of cows and their milk production in loose housing. Applied Animal Ethology 9: 121-129.

Kratzer D.D., Netherland W.M., Pulse R.E., Baker J.P., 1977. Maze learning in Quarter horses. Journal of Animal Science 46: 896-902.

Larkin S. and McFarland D., 1978. The cost of changing from one activity to another. Animal Behaviour 26: 1237-1246.

Lattal K.A., 1991. Scheduling positive reinforcers. In: Iverson I.H., Lattal K.A. (Editors), Experimental analysis of behaviour: Part 1. Elsevier. London UK. pp. 87-130.

Leonard F.C., O'Connell J., O'Farrell K., 1994. Effect of different housing conditions on behaviour and foot lesions in Friesian heifers. Veterinary Record 134: 490-494.

Lewis N.J. and Hurnik J.F., 1979. Stimulation of feeding in neonatal turkeys by flashing lights. Applied Animal Ethology 5: 161-171.

van der Linde R. and Lubberink J., 1992. Robotic milking (RMS): design and performance. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking. Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 23-32.

Lindley D.V. and Scott W.F., 1990. New Cambridge elementary statistical tables. Cambridge University Press, Cambridge UK.

Little W., Herriman I.D., Harrison R.D., 1984. Relationship between oestrus behaviour and frequency of visits made by dairy cows to out-of-parlour concentrate dispensers. Veterinary Record 114: 613-614.

Lorenz K.Z., 1950. The comparative method in studying innate behaviour patterns. Symposia of the Society of Experimental Biology 4: 221-268.

Lundqvist P., 1992. Human aspects in automatic milking. In: Ipema A.H., Lippus

A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific publishers, Wageningen, Netherlands. pp. 414-420.

MacKay P.C. and Wood-Gush D.G.M., 1980. The responsiveness of beef calves to novel stimulation: An interaction between exploration and fear. Applied Animal Ethology 6: 383-384.

MacMillan S., 1996. What is poor health and fertility costing your business? Dairy Farmer, February: 22-23.

Maier S.F. and Seligman E.P., 1976. Learned helplessness: Theory and Evidence. Journal of Experimental Psychology 105: 3-46.

Manning, A., 1979. An introduction to animal behaviour. Third Edition. Arnold. London, UK.

Marinier S.L. and Alexander A.J., 1994. The use of a maze in testing learning and memory in horses. Applied Animal Behaviour Science 39: 177-182.

Matthews L.R. and Temple W., 1979. Concurrent schedule assessment of food preference in cows. Journal of the Experimental Analysis of Behaviour 32: 245-254.

Mayer H., Schams D., Worstorff H., Prokopp A., 1984. Secretion of oxytocin and milk removal as affected by milking cows with and without manual stimulation. Journal of Endocrinology, 103: 355-361.

McDonald P., Edwards R.A., Greenhalgh J.F.D., 1988. Animal Nutrition. Longman Scientific and Technical. London, UK.

McFarland D.J., 1989. Animal Behaviour. Longman Scientific and Technical, Harlow UK.

McFarland D.J., 1977. Decision making in animals. Nature, 269: 15-21.

Metcalf J.A., Roberts S.J., Sutton J.D., 1992. Variations in blood flow to and from the bovine mammary gland measured using transit time ultrasound and dye dilution. Research in Veterinary Science 53: 59-63.

Metz J.H.M., 1983. Food competition in cattle. In: Baxter S.H., Baxter M.R. and MacCormack J.A.D. (Editors), Farm animal housing and welfare. Martinus Nijhoff. Netherlands, pp. 164-170.

Metz J.H.M., 1984/85. The reaction of cows to a short-term deprivation of lying. Applied Animal Behaviour Science 13: 301-307.

Metz-Stefanowska J., Huijsman P.J.M., Hogewerf P.H., Ipema A.H., Keen A., 1992. Behaviour of cows before during and after milking with an automatic system. In:

Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 278-288.

Miller K. and Wood-Gush D.G.M., 1991. Some effects of housing on the social behaviour of dairy cows. Animal Production 53: 271-278.

Moore C.L., Whittlestone W.G., Mullord M., Priest P.N., Kilgour R., Albright J.L., 1974. Behavioural responses of dairy cows in a simple operant conditioning chamber. Journal of Dairy Science 57: 631.

Morrison W.D. and Curtis S.E., 1983. Observations of experimental thermoregulation by chicks. Poultry Science 62: 1912-1914.

Morrison W.D. and McMillan I., 1985. Operant control of the thermal environment by chicks. Poultry Science 64: 1656-1660.

Morrison W.D. and McMillan I., 1986. Response of chicks to various environmental temperatures. Poultry Science 65: 881-883.

Morrison W.D., Bate L.A., Amyot E., McMillan I., 1987. Performance of large groups of chicks using operant conditioning to control the thermal environment. Poultry Science 66: 1758-1761.

Mottram T.T., Hall R.C., Spencer D.S., Allen C.J., Winter A., 1995. The role of the cow in automatic teat cup attachment. Journal of Dairy Science 78: 1873-1880.

Mottram T. and Street M., 1992. Robots get to grips with cows. New Scientist, October: 23-24.

Muller C.J.C., Botha J.A., Smith W.A., Coetzer W.A. (1994): Response of cows to a shade structure in a temperate climate. Dairy systems for the 21st century. Proceedings of the third international dairy housing conference. 2-5 February 1994, Orlando, Florida. American society of agricultural engineers.

Murphey R.M., Duarte F.A.M., Novaes W.C., Penedo M.C.T., 1981. Age group differences in bovine investigatory behaviour. Developmental Psychobiology 14:117-125.

Mwangali S., Schmidt D., Ellendorf F., 1982/3. A multiple free choice model for pigs. Applied Animal Ethology 9: 263-271.

Nickerson S.C., 1992. Anatomy and physiology of the udder. In: Bramley A.J., Dodd F.H., Mein G.A. and Bramley J.A. (Editors), Machine milking and lactation. Insight books. Burlington, USA. pp. 37-68.

Nicol C.J., Blakeborough A., Scott G.B., 1991. Aversiveness of motion and noise to broiler chickens. British Poultry Science 32: 249-260.

Nicol C.J., 1987. Behavioural responses of laying hens following a period of spatial restriction. Animal Behaviour 35: 1709-1719.

Nicol C.J., 1996. Farm animal cognition. Animal Science 62: 375-391.

Nombekela S.W., Murphy M.R., Gonyou H.W., Marden J.I., 1994. Dietary preferences in early lactation cows as affected by primary tastes and some common feed flavours. Journal of Dairy Science 77: 2393-2399.

O'Connell J.M., Giller P.S., Meaney W.J., 1992. Factors affecting cubicle utilisation by dairy cattle using stall frame and bedding manipulation experiments. Applied Animal Behaviour Science 35: 11-21.

Odde K.G., Kiracofe G.H., Schalles R.R., 1985. Suckling behaviour in range beef calves. Journal of Animal Science 61: 307-310.

Ordolff D., 1987. Safety considerations for automatic milking. Journal of Agricultural Engineering 38: 91-98.

Pearce J.M., 1987. An introduction to animal cognition. Lawrence Erlbaum Associate Publishers, UK.

Phillips C.J.C., 1993. Cattle behaviour. Farming Press. Ipswich, UK.

Phillips C.J.C. and Schofield S.A., 1989. The effect of supplementary light on the production and behaviour of dairy cows. Animal Production 48: 293-303.

Phillips C.J.C. and Schofield S.A., 1994. The effect of cubicle and straw yard housing on the behaviour, production and hoof health of dairy cows. Animal Welfare 3: 37-44.

Phillips C.J.C. and Weiguo L., 1991. Brightness discrimination abilities of calves relative to those of humans. Applied Animal Behaviour Science 31: 25-33.

Pollard J.C., Littlejohn R.P., Suttie J.M., 1994. Responses of red deer to restraint in a y-maze preference test. Applied Animal Behaviour Science 39: 63-71.

Prescott N.B., 1992. Effects of stocking density, diet, age, CGI and weight on activity of dairy cows. University of Edinburgh Honours Thesis. May 1992.

Prescott S. (1994): Personal communication.

Rathore A.K., 1982. Order of cow entry at milking and its relationship with milk yield and consistency. Applied Animal Ethology 8: 45-52.

Restle F., 1957. Discrimination of cues in mazes: A resolution of the "place vs response" question. Psychological Review 64: 217-228.

Riol J.A., Sanchez J.M., Eguren V.G., Grandioso V.R., 1989. Colour perception in fighting cattle. Applied Animal Behaviour Science 23: 199-206.

Robertson G. (1991): Personal communication.

Rooijen J.V., 1982. The value of choice tests in assessing the welfare of domestic animals. Applied Animal Ethology 8: 295-299.

Rose S.P. and Kyriazakis I., 1991. Diet selection of pigs and poultry. Proceedings of the Nutrition Society 50: 87-98.

Rossing W., Ipema A.H., Veltman P.F., 1985. The feasibility of milking in a feeding box. IMAG. Wageningen, Netherlands. Report 85-2.

Royle C., Garnsworthy P.C., McArthur A.J., Mepham T.B., 1992a. Effects of frequent milking on heart rate and other physiological variables in dairy cattle. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc scientific publishers, Wageningen, Netherlands. pp. 237-243.

Royle C., Garnsworthy P.C., McArthur A.J., Mepham T.B., 1992b. Heart rate changes in dairy cows associated with milking. Journal of Physiology 446: 575P.

Ruckebusch Y., 1972. The relevance of drowsiness in the circadian cycle of farm animals. Animal Behaviour 20: 637-643.

Ruckebusch Y., 1974. Sleep deprivation in cattle. Brain Research 78: 495-499.

Ruckebusch Y., Dougherty R.W., Cook H.M., 1974. Jaw movements and rumen motility as criteria for measurement of deep sleep in cattle. American Journal of Veterinary Research 35: 1309-1312.

Rushen J., 1986. Aversion of sheep for handling treatments: Paired-choice studies. Applied Animal Behaviour Science 16: 363-370.

Rutter S.M., Jackson D.A., Johnson C.L., Forbes J.M., 1987. Automatically recorded competitive feeding behaviour as a measure of social dominance in dairy cows. Applied Animal Behaviour Science 17: 41-50.

Sagi R., Gorewit R.C., Merrill W.G., Wilson D.B., 1980. Premilking stimulation effects on milking performance and oxytocin and prolactin release in cows. Journal of Dairy Science 63: 800-806.

Schaeffer R.G. and Sikes J.D., 1971. Discrimination learning in dairy calves. Journal of Dairy Science 54: 1971.

Schein M.W. and Fohrman M.H., 1955. Social dominance relationships in a herd of dairy cattle. British Journal of Animal Behaviour 3: 45-55.

Schmisseur W.E., Albright J.L., Dillon W.M., Kehberg E.W., Morris W.H.M., 1966. Animal behaviour responses to loose and free-stall housing. Journal of Dairy Science 49: 102-104.

Schon H., Artmann R., Worstaff H., 1992. The automation of milking as a key issue in future oriented dairy farming. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 7-22.

Seabrook M.F., 1992. The perception by stock persons of the effect on their esteem, self-concept and satisfaction of the incorporation of automatic milking into their herds. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 409-413.

Seabrook M.F., 1994. Psychological interactions between the milker and the dairy cow. In: 33rd. annual meeting national mastitis council, inc. Jan 31-Feb 2. National mastitis council, Orlando, Florida, pp. 163-174.

Senatore E.M., Butler W.R., Oltenacu P.A., 1996. Relationships between energy balance and post-partum ovarian activity and fertility in first lactation dairy cows. Animal Science 62: 17-23.

Sibly R. and McFarland D., 1974. A state-space approach to motivation. In: McFarland D. (Editors), Motivational control systems analysis. Academic Press, London UK, pp. 213-250.

Siegel S., 1974. Nonparametric statistics for the behavioural sciences. McGraw-Hill Kogakusha, London UK.

Silveira P.A., Spoon R.A., Ryan D.P., 1993. Evidence for maternal behaviour as a requisite link in suckling-mediated anovulation in cows. Biology of Reproduction 49 1338-1346.

Singh S.S., Ward W.R., Lautenbach K., Murray R.D., 1993. Behaviour of lame and normal dairy cows in cubicles and in a straw yard. Veterinary Record 133: 204-208.

Smith M., 1993. British farmers pass judgement on robots and rotaries. Dairy Farmer, November: 50-51.

Soffie M., Thines G., Marneffe D. G, 1976. Relation between milking order and dominance value in a group of dairy cows. Applied Animal Ethology 2: 271-276.

Spence K.W. and Lippitt R., 1948. An experimental test of the sign-gestalt theory of trial and error learning. Journal of Experimental Psychology 36: 491-502.

Spencer D.S. and Street M.J., 1992. The design of the management system for the Silsoe automatic milking system. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific publishers, Wageningen, Netherlands. pp. 309-314.

Stevenson J.S., Knoppel E.L., Minton J.E., Salfen B.E., Gaverick H.A., 1994. Estrus, ovulation, luteinizing hormone, and suckling induced hormones in mastectomised cows with and without unrestricted presence of the calf. Journal of Animal Science 72:690-699.

Stewart P.H., Arave C.W., Dias B., 1992. The effect of observation on Holstein heifers' learning ability in a closed field maze. Journal of Animal Science 70: 155.

Street M.J., Hall R.C., Spencer D.S., Wilkin A.L., Mottram T.T., Allen C.J., 1992. Design principles for the Silsoe automatic milking system. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific publishers, Netherlands, pp. 40-48.

Svennersten K. and Samuelsson B., 1992. The effect of feeding during milking on milk production and milk flow. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 233-236.

Svennersten K. and Samuelsson B., 1993. Should cows be given concentrate in conjunction with milking. Dairy Science Abstracts 56: 352.

Svennersten K., Nelson L., Gorewit R., Uvnas-Moberg K., 1990. Simultaneous feeding during milking enhances milking-related oxytocin secretion in dairy cows whereas atropinization and food deprivation decreases it. In: Svennersten K. (Editors), Central and local mechanism involved in the control of milk production and milk let down. Swedish university of agricultural sciences, Uppsala Sweden. pp. VII 1-16.

Svennersten K., Gorewit R.C., Sjaunja L.O., Uvnas-Moberg K., 1995. Feeding during milking enhances milking-related oxytocin secretion and milk production in dairy cows whereas food deprivation decreases it. Acta Physiologica Scandinavia 153: 309-310.

Tancin V., Broucek J., Harcek L., Uhrincat M., Mihina S., Cupka P. (1994): Suckling- Machine milking influenced secretion of oxytocin, cortisol and milking characteristics in primiparous dairy cows. Dairy systems for the 21st century. Proceedings of the third international dairy housing conference. 2-5 February 1994, Orlando, Florida. American society of agricultural engineers.

Tanner M., Grandin T., Cattell M., Deesing M., 1994. The relationship between facial hair whorls and milking parlour side preferences. Journal of Animal Science 72

Supplement 1: 207.

Thomson K. (1994): Personal communication.

Thorhallsdottir A.G., Provenza F.D., Balph D.F., 1987. Food aversion learning in lambs with or without a mother: Discrimination, Novelty and persistence. Applied Animal Behaviour Science 18: 327-340.

Toates F., 1980. Animal behaviour a systems approach. John Wiley and Son. Chichester, UK.

Tolman E.C., 1951. Collected papers in psychology. University of California Press. California, USA.

Trivers R.L., 1974. Parent-offspring conflict. American Zoologist 14: 249-264.

Tulloh N.M., 1961. Behaviour of cattle in yards. II. A study of temperament. Animal Behaviour 9: 25-30.

Uetake K. and Kudo Y., 1994. Visual dominance over hearing in feed acquisition procedure of cattle. Applied Animal Behaviour Science 42: 1-9.

Ventorp M., Michanek P., 1991. Cow-calf behaviour in relation to first suckling. Research in Veterinary Science 51: 6-10.

Walker S., 1987. Animal learning an introduction. Routledge and Kegan Paul, London UK.

Walton A. (1994): Personal communication.

Warren J.M., 1960. Reversal learning by Paradise fish *(Macropodus opercularis)*. Journal of Comparative Physiological Psychology 53: 276-378.

Warren J.M. and Warren H.B., 1962. Reversal learning by horse and racoon. Journal of Genetic Psychology 100: 215-220.

Watson P. (1994): Personal communication.

Webster A.J.F., 1983. Understanding the dairy cow. BSP Professional Books, London UK.

Webster J., 1995. Animal welfare a cool eye towards eden. Blackwell science. London, UK.

Whipp J.I., 1992. Design and performance of milking parlours. In: Bramley A.J., Dodd F.H., Mein G.A. and Bramley J.A. (Editors), Machine milking and lactation. Insight Books, Burlington USA, pp. 285-310.

Wieckert D.A., Johnson L.P., Offord K.P., Barr G.R., 1966. Measuring learning ability in dairy cows. Journal of Dairy Science 49: 63.

Wiepkema P.R., 1983. Umwelt and animal welfare. In: Baxter S.H., Baxter M.R. and MacCormack J.A.D. (Editors), Farm animal housing and welfare. Martinus Nijhoff, Netherlands, pp. 45-49.

Wierenga H.K. and Hopster H., 1987. Behavioural research for the further development of systems for automatic concentrate feeding. Proceedings of the 3rd symposium on automation in dairying. IMAG. Wageningen, Netherlands. pp 52-61.

Wierenga H.K. and Hopster H., 1988. Effects of changes in timing of automatic concentrate feeding on the behaviour of dairy cows. In: Unshelm J.van, Putten G., Zeeb K. and Ekesbo I. (Editors), Proceedings of the international congress on applied ethology of farm animals. Skara, Sweden. pp 273-279.

Wilde C.J. and Peaker M., 1990. Autocrine control of milk production. Journal of Agricultural Science 114: 235-238.

Williams B.A., 1994. Reinforcement and choice. In: Animal learning and cognition. Mackintosh N.J. (Editor). Academic Press. London UK. pp 81-105.

Williams G.L., 1990. Suckling as a regulator of postpartum rebreeding in cattle: A review. Journal of Animal Science 68: 831-852.

Willis G.L. and Mein G., 1982/83. Classical conditioning of milk ejection using a novel conditioning stimulus. Applied Animal Ethology 9: 231-237.

Winter A., 1993. The behaviour and modification of inherent behaviour patterns of dairy cows under frequent and automatic milking management. Ph.D. Dissertation, Reading University.

Winter A., Teverson R.M., Hillerton J.E., 1992. The effect of increased milking frequency and automated milking systems on the behaviour of the dairy cow. In: Ipema A.H., Lippus A.C., Metz J.H.M. and Rossing W. (Editors), Prospects for automatic milking: Proceedings of the international symposium on prospects for automatic milking. Pudoc Scientific Publishers, Wageningen, Netherlands. pp. 261-269.

Young GB., Lee GJ., Waddington D., Sales DI., Bradley JS., Spooner RL., 1983. Culling and wastage of dairy cows in East Anglia. Veterinary Record 113:107-111.

Yungblut D.H., Albright J.L., Hill D.L., Moeller N.J., 1974. Effect of stall location and surface material upon cow preference, stall use, cleanliness, udder health. and laterality in free stall dairy barns. Journal of Dairy Science 57: 630.